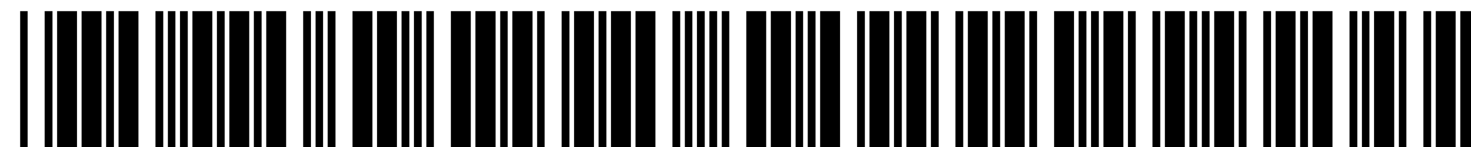


(12) **United States Patent**
Kojima et al.

(10) **Patent No.: US 8,309,858 B2**
(45) **Date of Patent: Nov. 13, 2012**

(54) **ELECTRICAL DEVICE INCLUDING A FUNCTIONAL ELEMENT IN A CAVITY**

(75) Inventors: **Akihiro Kojima**, Yokohama (JP); **Yoshiaki Sugizaki**, Yokohama (JP); **Yoshiaki Shimooka**, Machida (JP)

(73) Assignee: **Kabushiki Kaisha Toshiba**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 249 days.

(21) Appl. No.: **12/358,869**

(22) Filed: **Jan. 23, 2009**

(65) **Prior Publication Data**

US 2009/0188709 A1 Jul. 30, 2009

(30) **Foreign Application Priority Data**

Jan. 25, 2008 (JP) 2008-015510
Oct. 31, 2008 (JP) 2008-282499

(51) **Int. Cl.**
H05K 1/16 (2006.01)

(52) **U.S. Cl.** **174/260**

(58) **Field of Classification Search** .... None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,770,923 A 9/1988 Wasa et al.
5,144,536 A * 9/1992 Tsukada et al. 361/765
5,589,082 A 12/1996 Lin et al.
6,747,356 B2 * 6/2004 Ando et al. 257/758
6,936,494 B2 8/2005 Cheung
7,129,420 B2 * 10/2006 Hashimoto 174/260
7,145,213 B1 12/2006 Ebel et al.
7,855,342 B2 * 12/2010 Sakamoto et al. 174/260
2006/0012028 A1 * 1/2006 Usui et al. 257/700
2007/0158769 A1 7/2007 You
2007/0249082 A1 10/2007 Hanaoka et al.
2008/0006910 A1 1/2008 Miyata et al.
2008/0274576 A1 * 11/2008 Enomoto et al. 438/51
2010/0187502 A1 * 7/2010 Gambino et al. 257/24

FOREIGN PATENT DOCUMENTS

JP 2006-7459 1/2006

OTHER PUBLICATIONS

U.S. Appl. No. 12/575,778, filed Oct. 8, 2009, Kojima, et al.
U.S. Appl. No. 12/255,144, filed Oct. 21, 2008, Takeshi Miyagi, et al.
J. L. Pornin, et al., "Wafer Level Thin Film Encapsulation for BAW RF MEMS", Electronic Components and Technology Conference, 2007, pp. 605-609.

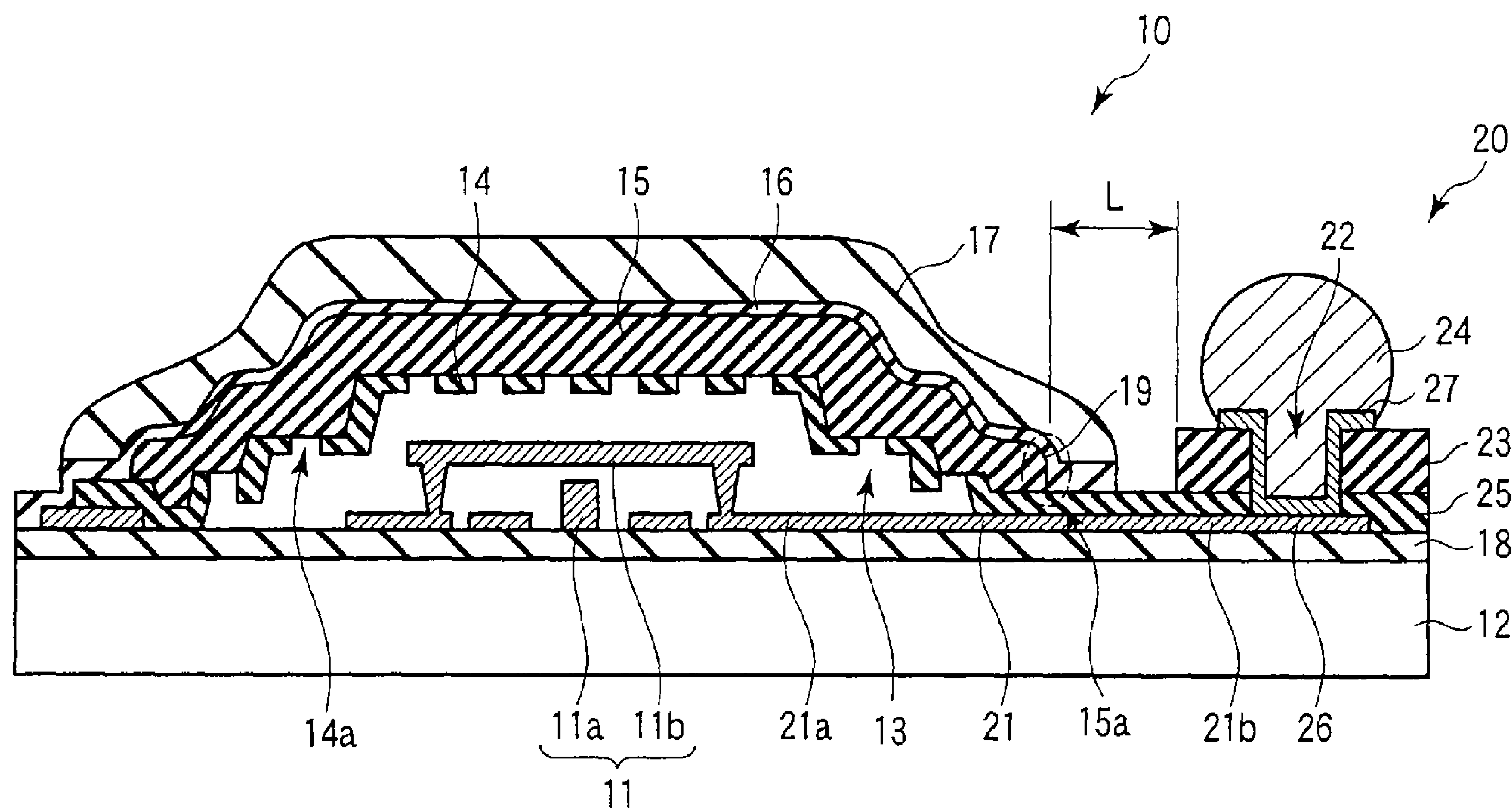
* cited by examiner

Primary Examiner — Jeremy Norris
Assistant Examiner — Tremesha S Willis
(74) *Attorney, Agent, or Firm* — Oblon, Spivak, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

A substrate includes a functional element. An insulating first film forms a cavity which stores the functional element, together with the substrate, and includes a plurality of through-holes. An insulating second film covers the plurality of through-holes, is formed on the first film, and has a gas permeability which is higher than that of the first film. An insulating third film is formed on the second film and has a gas permeability which is lower than the second film. An insulating fourth film is formed on the third film and has an elasticity which is larger than the third film.

26 Claims, 10 Drawing Sheets



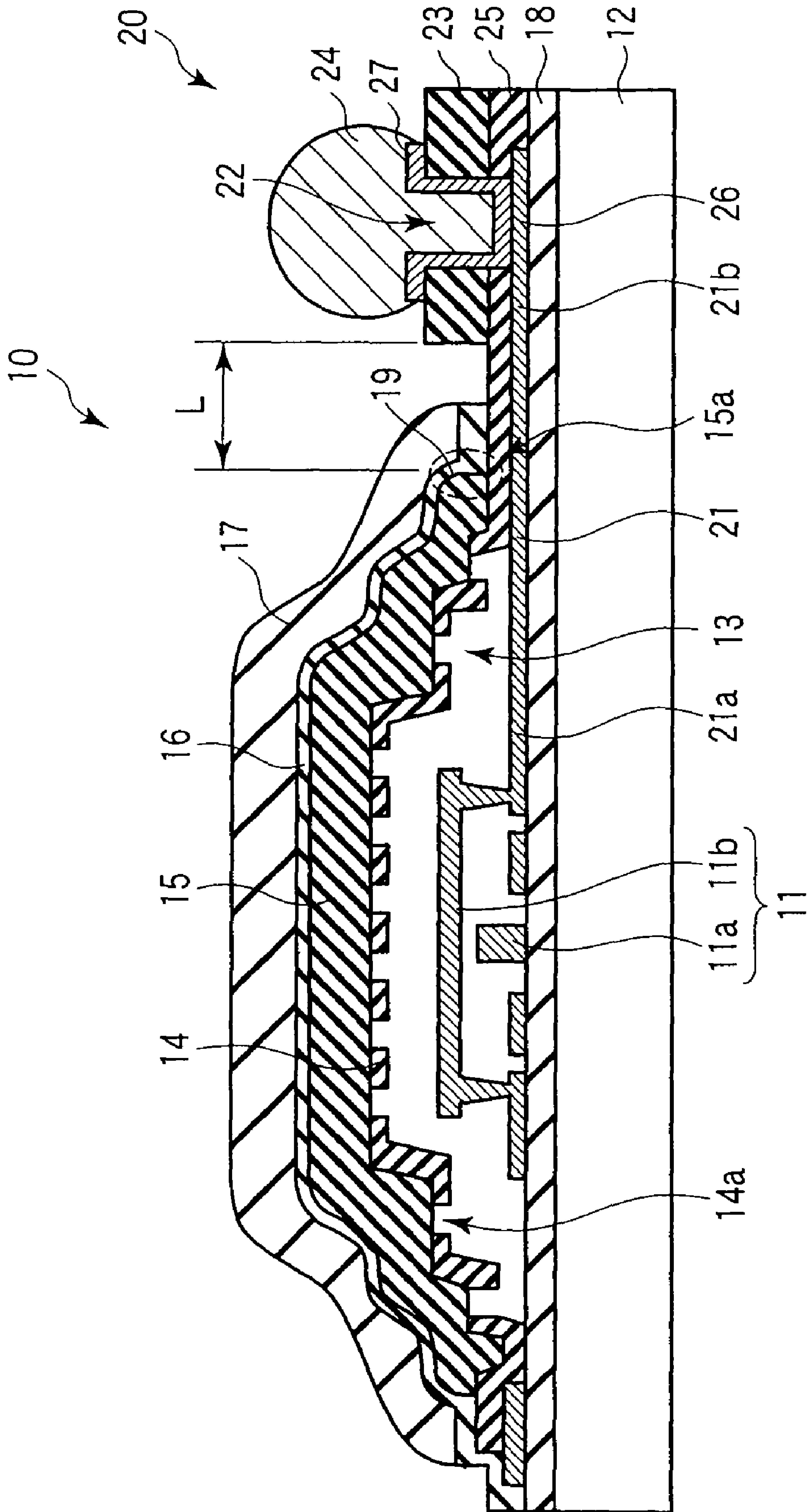


FIG. 1

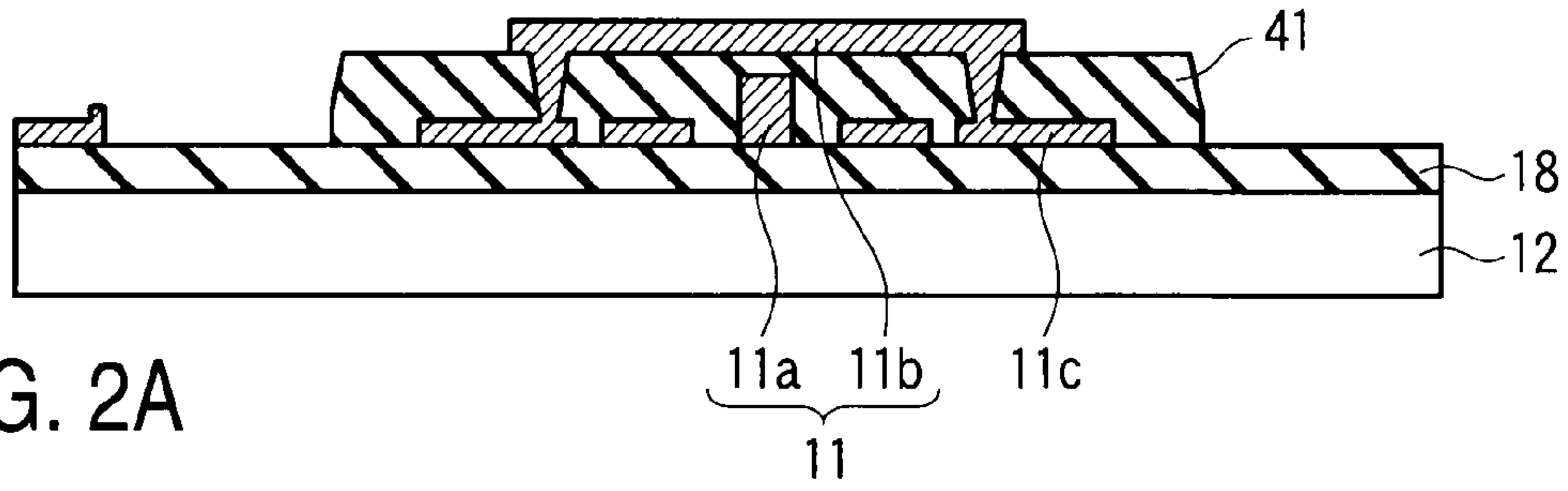


FIG. 2A

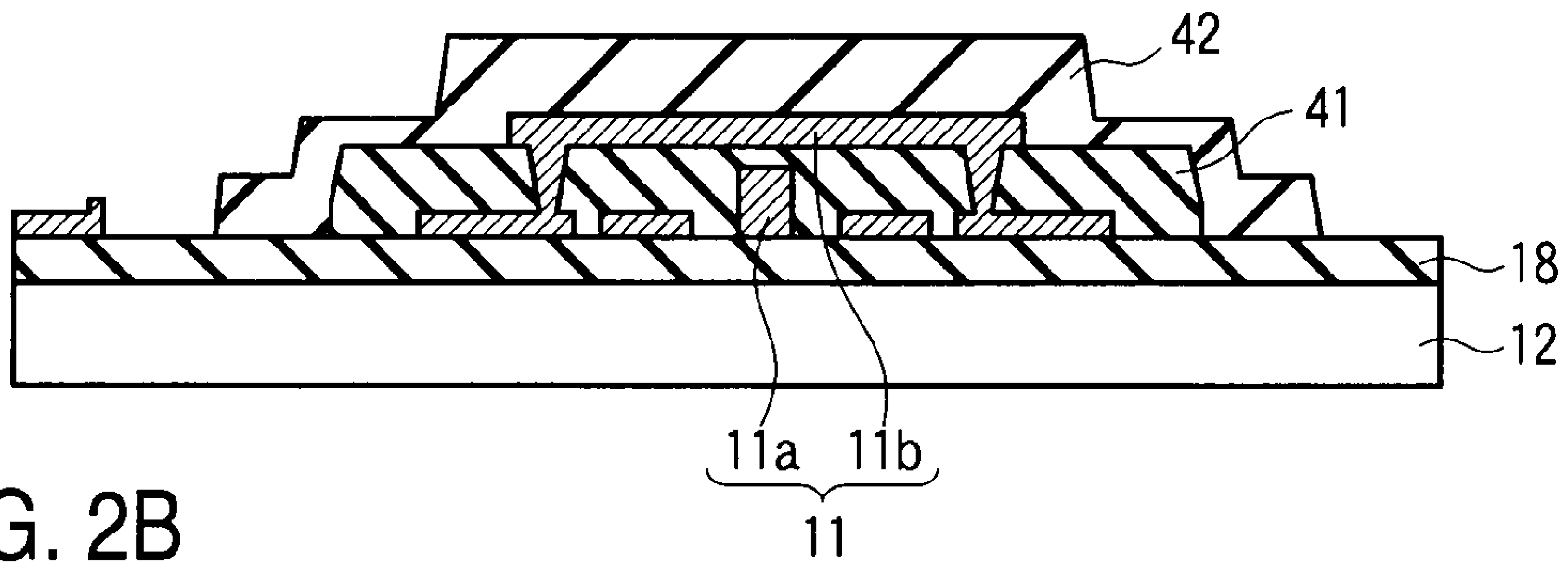


FIG. 2B

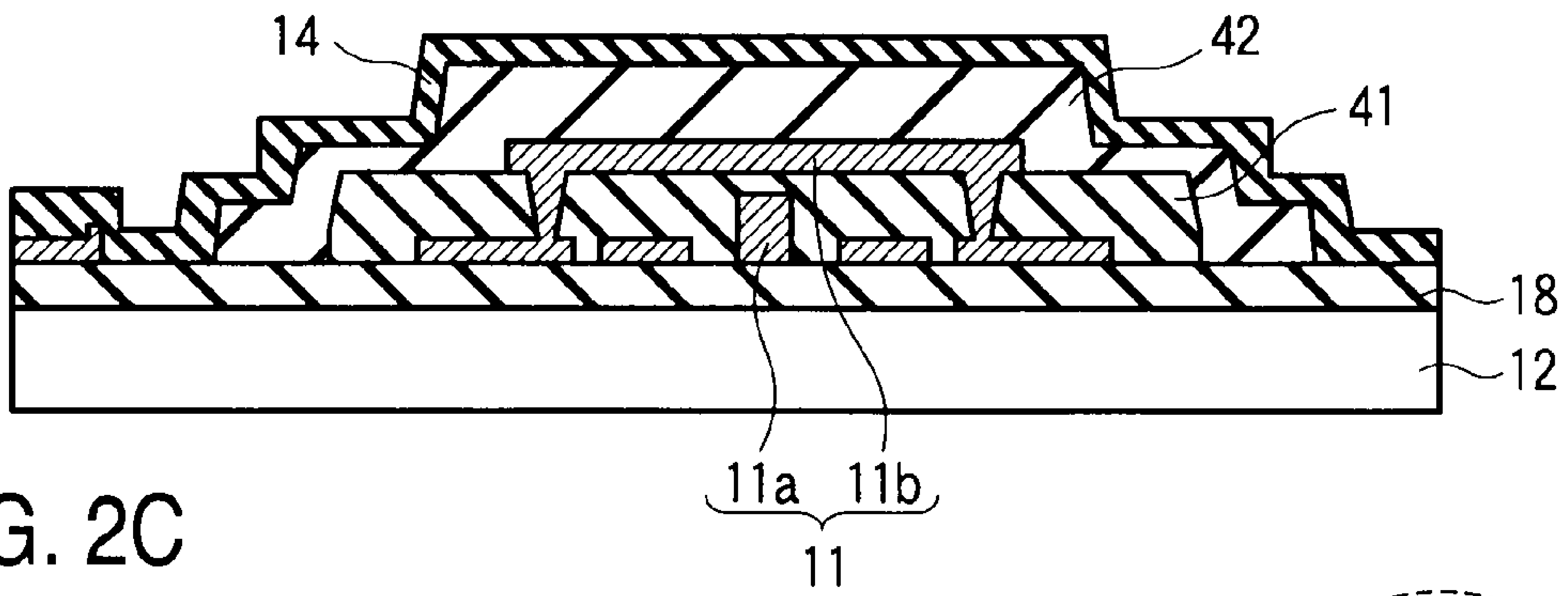


FIG. 2C

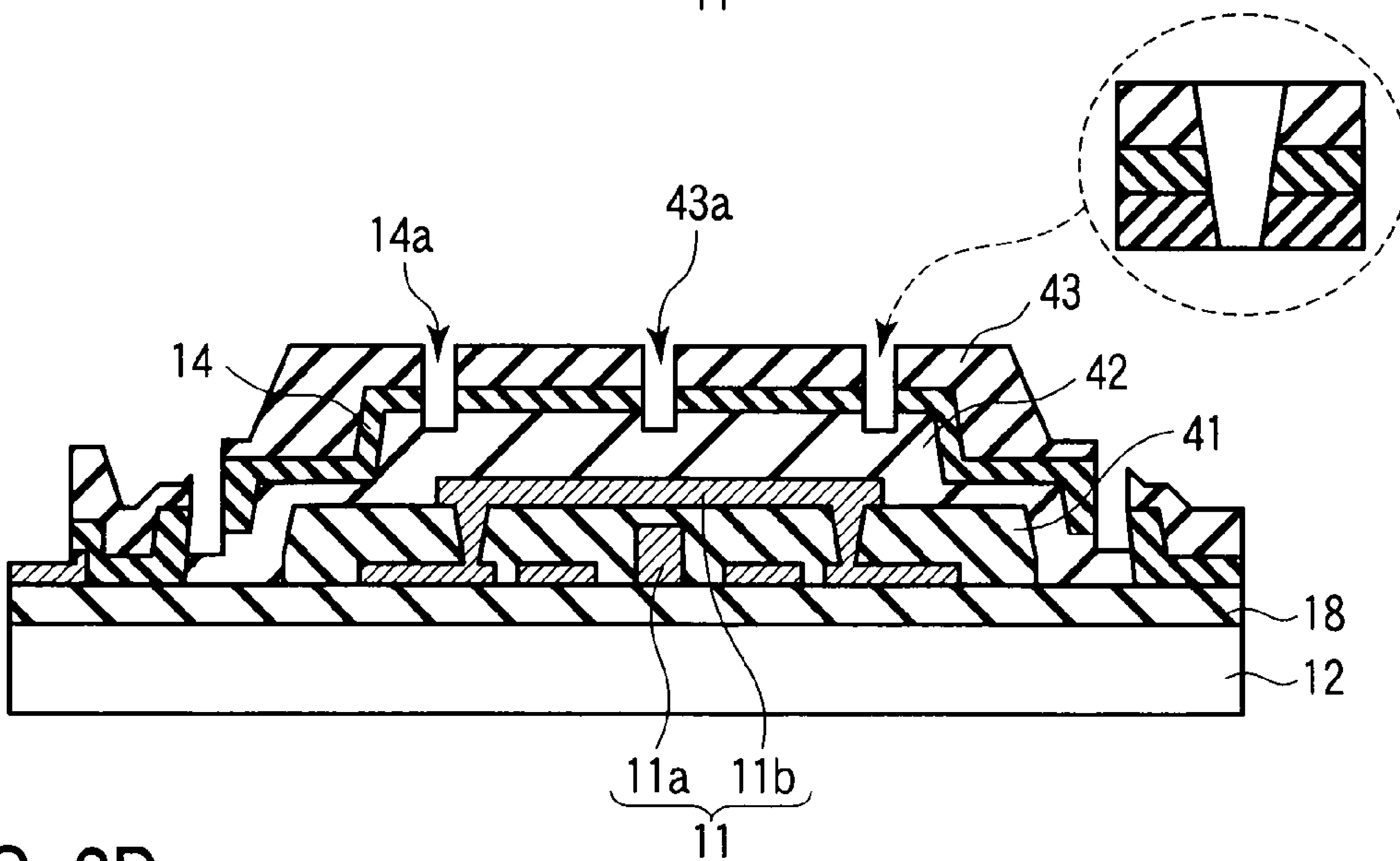
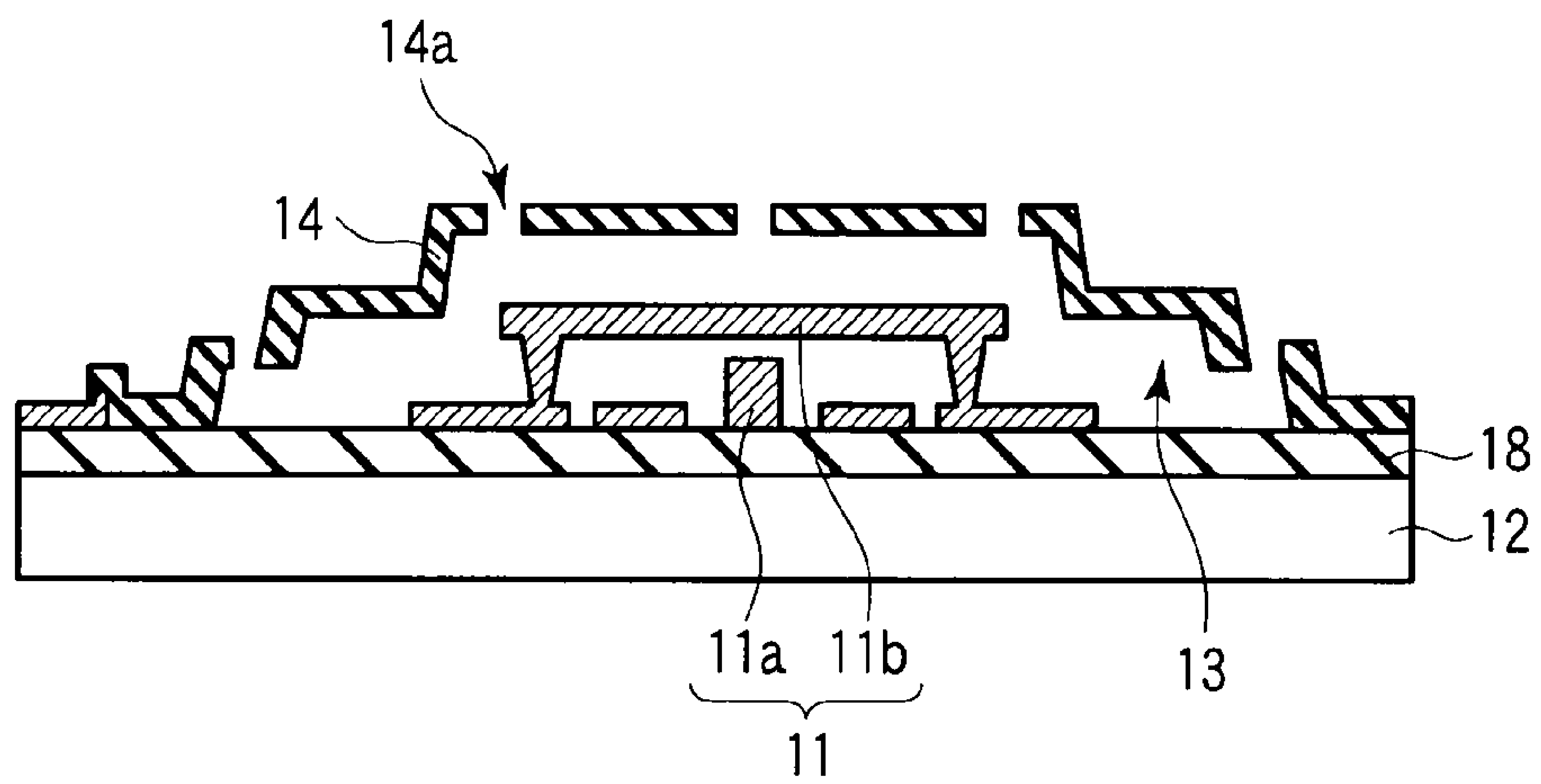
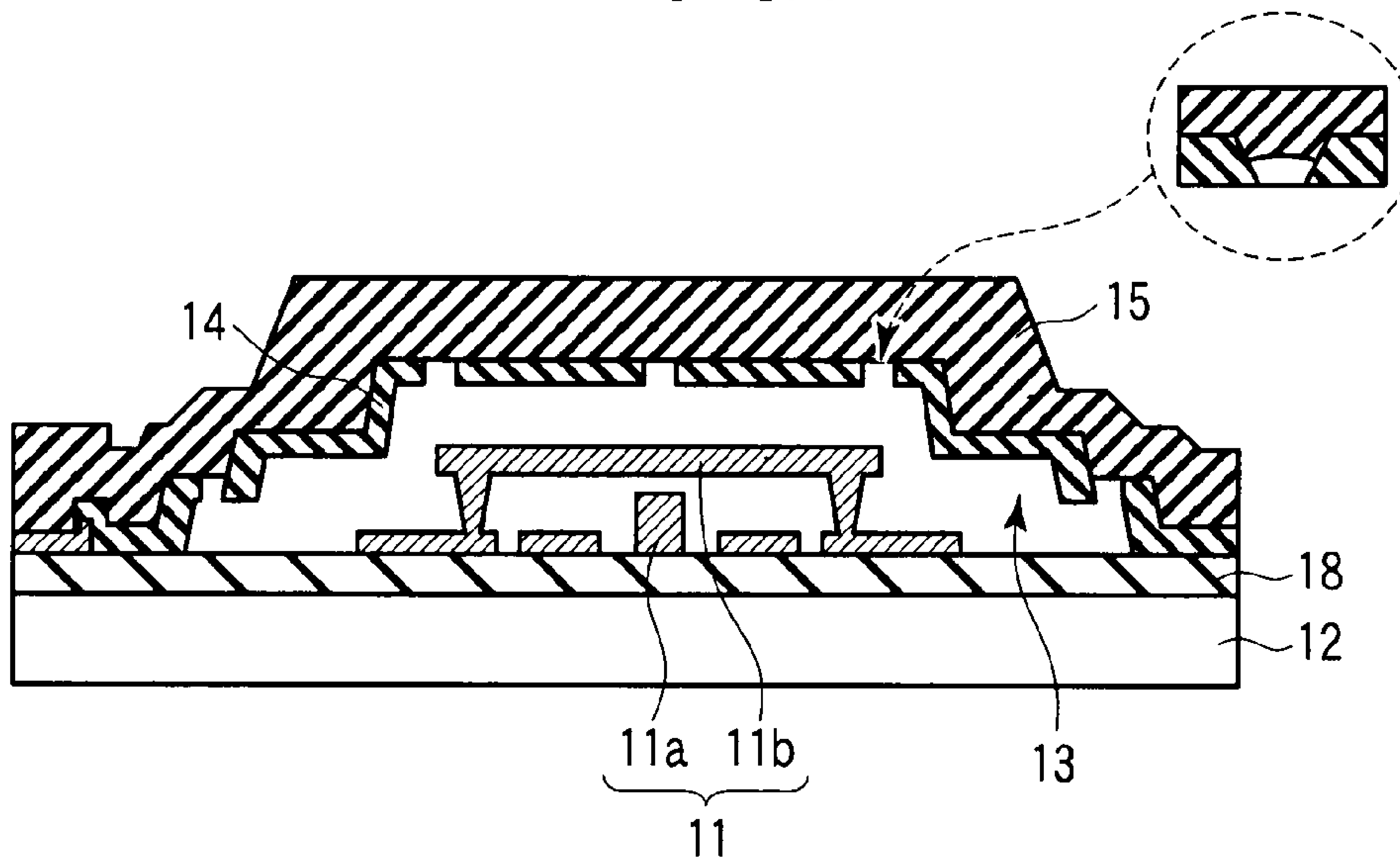


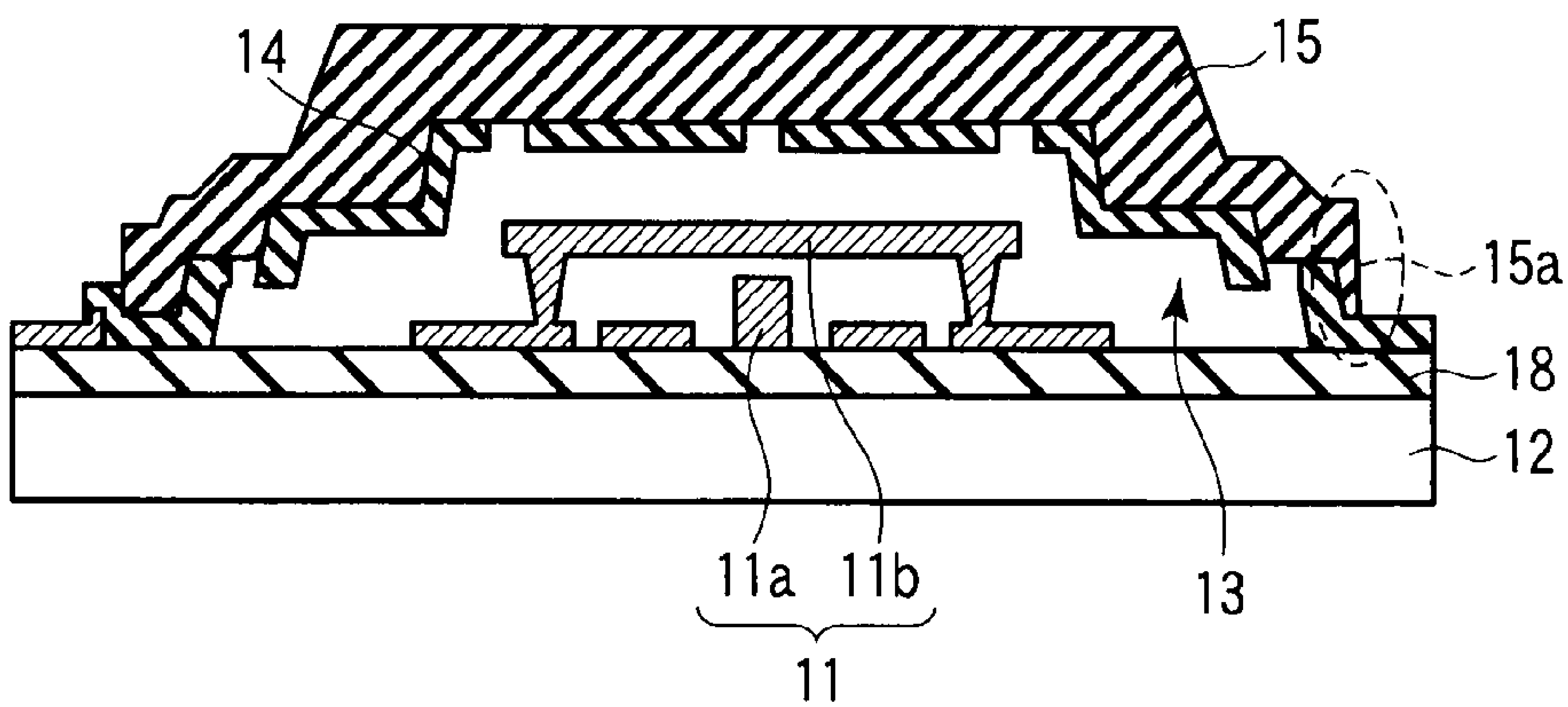
FIG. 2D



F I G. 3A



F I G. 3B



F I G. 3C

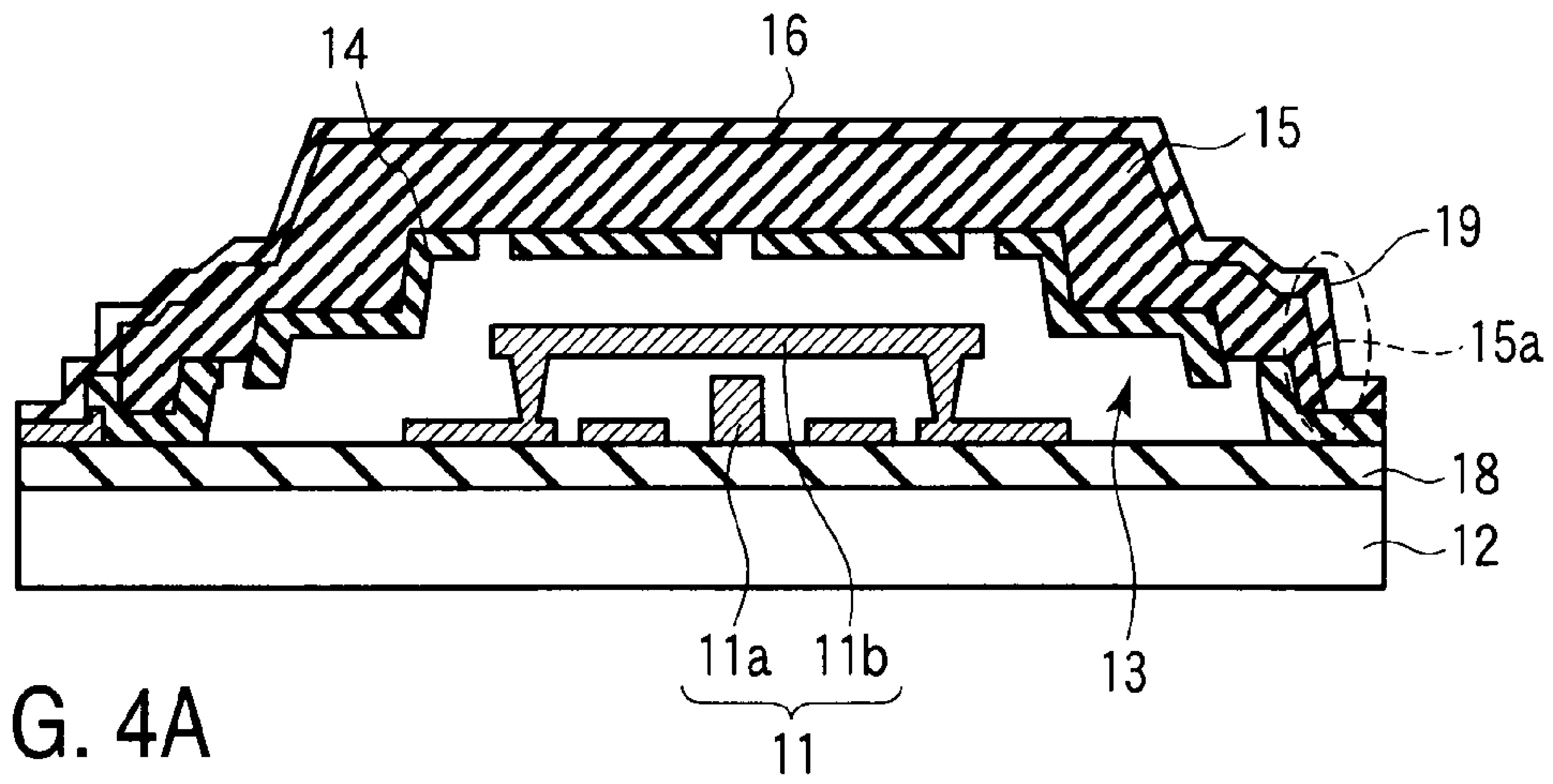


FIG. 4A

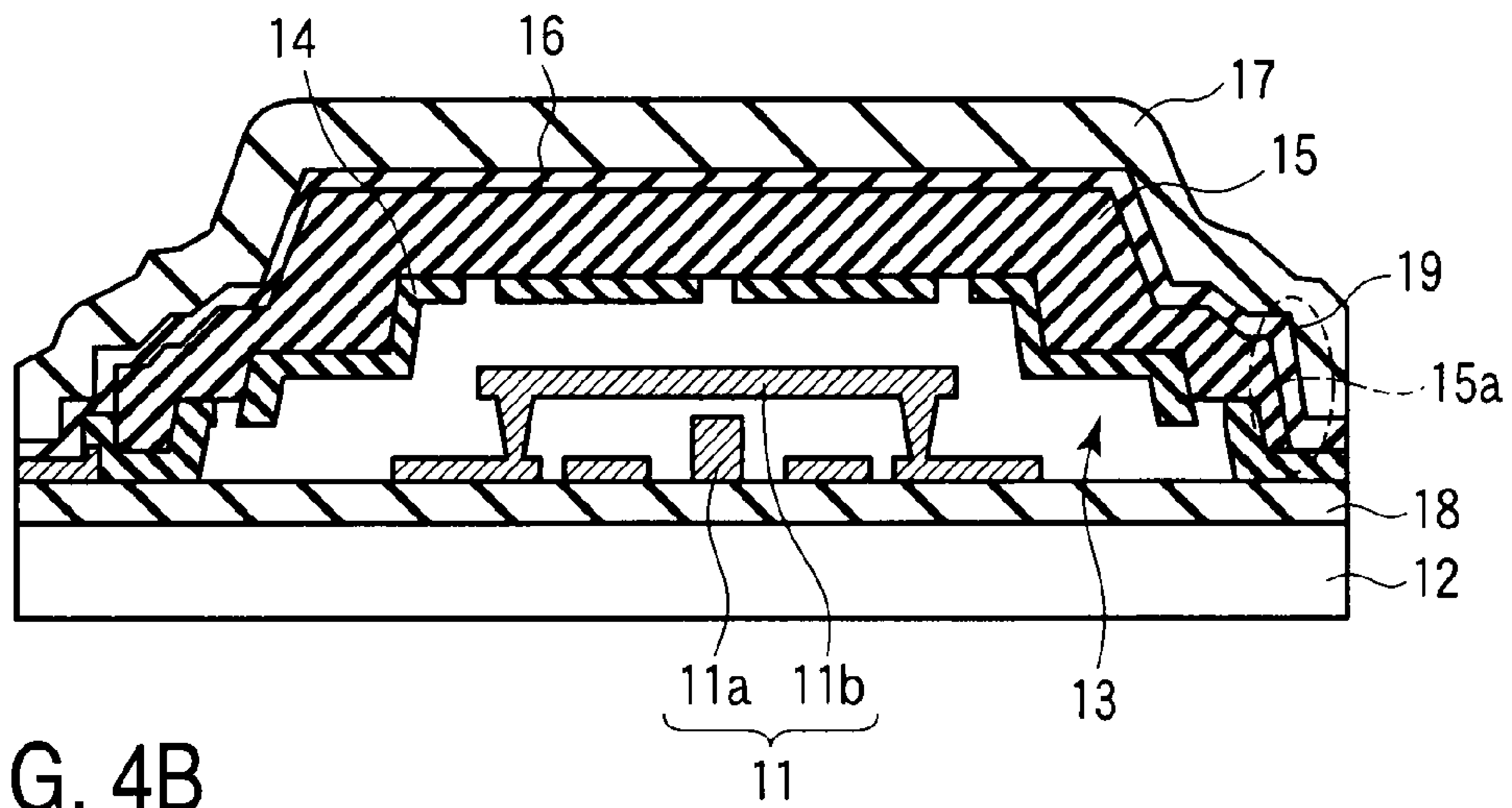


FIG. 4B

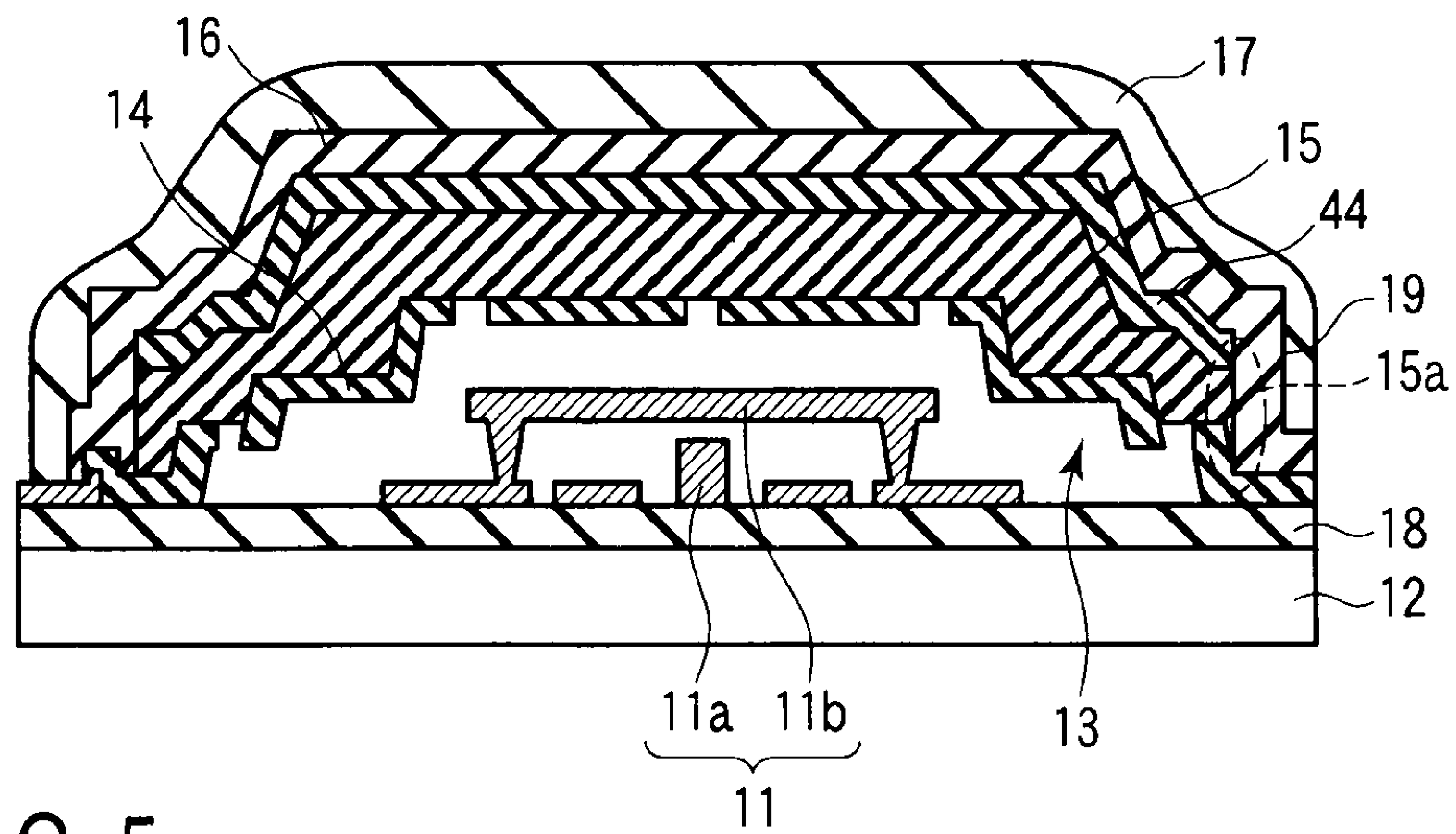
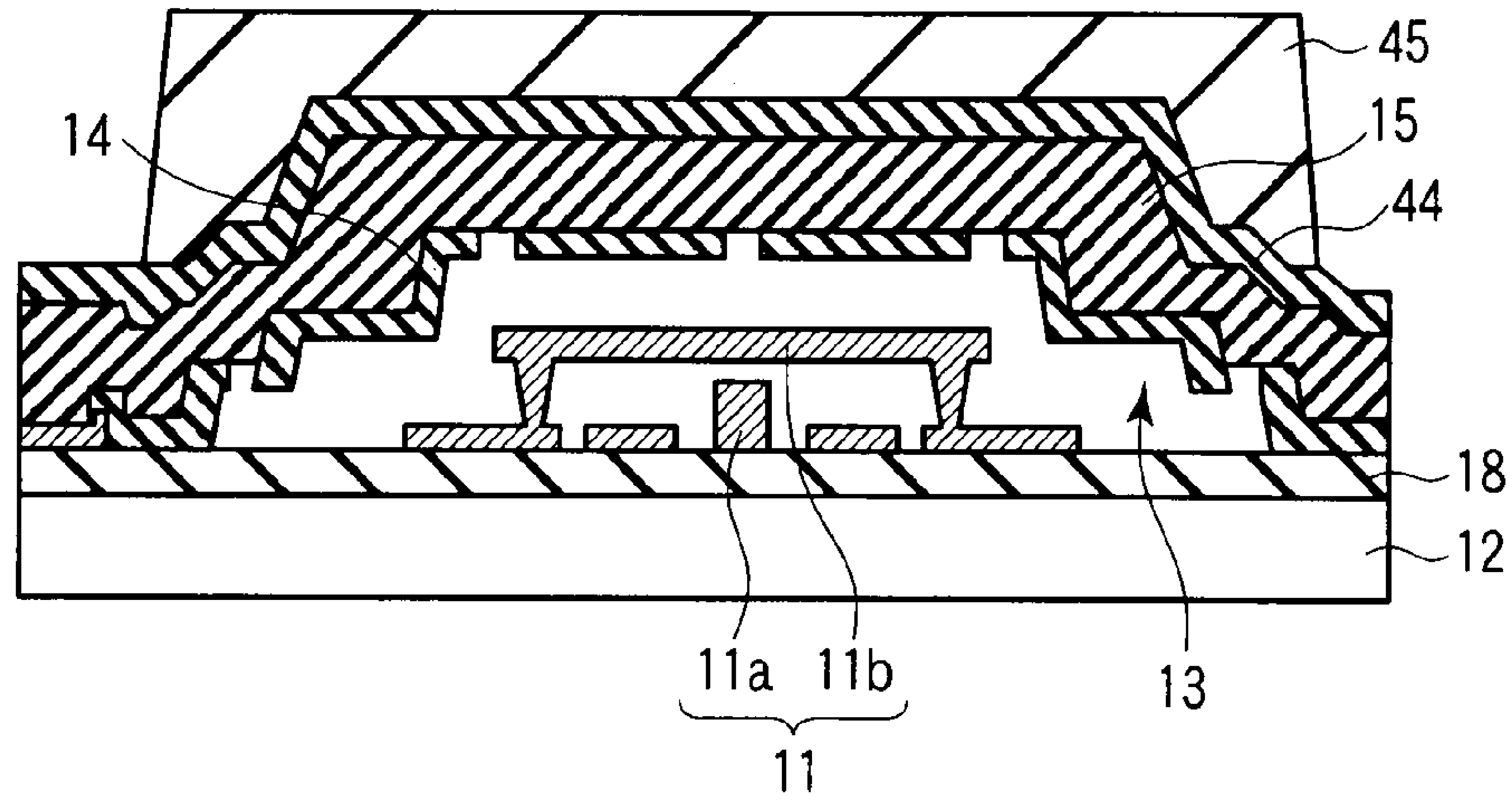
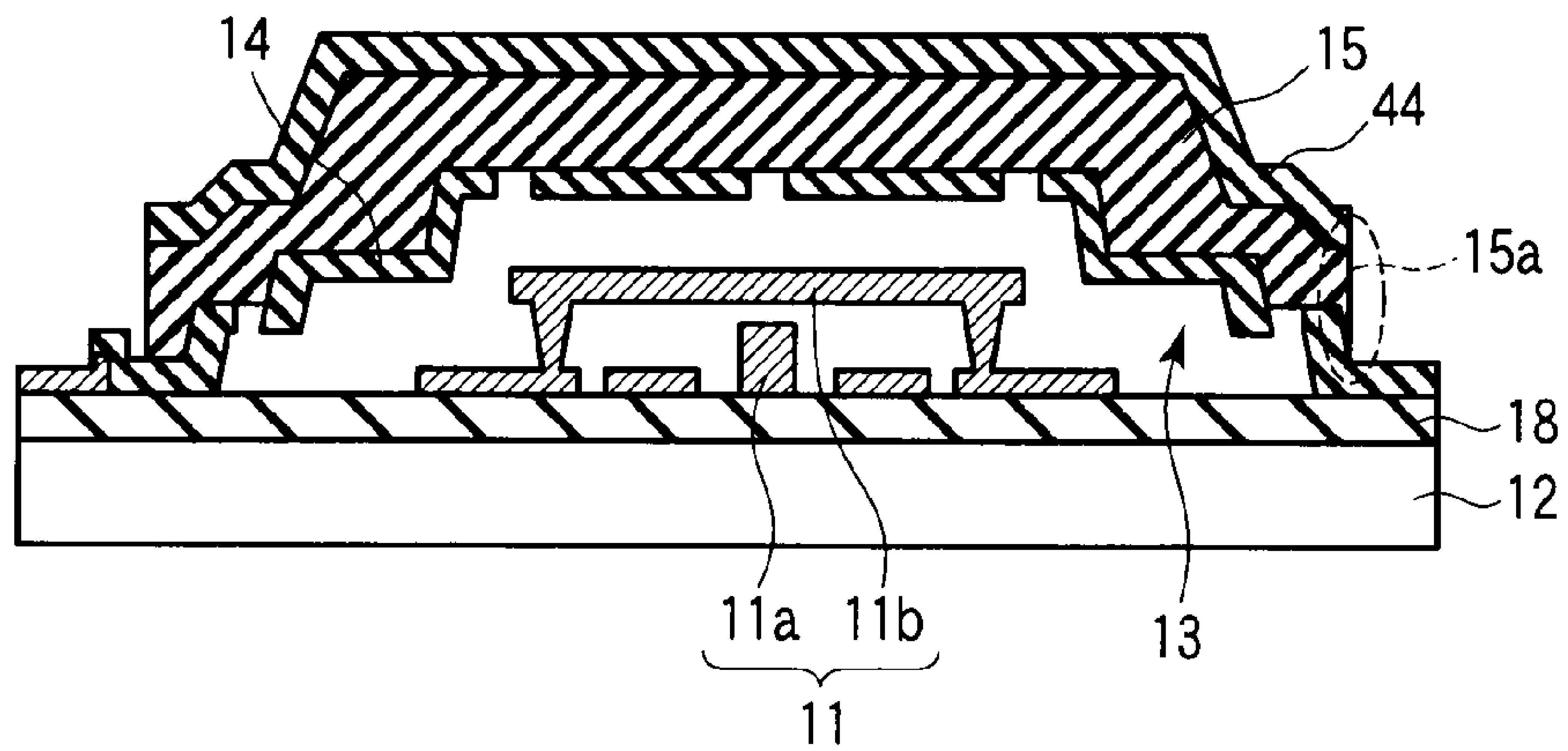


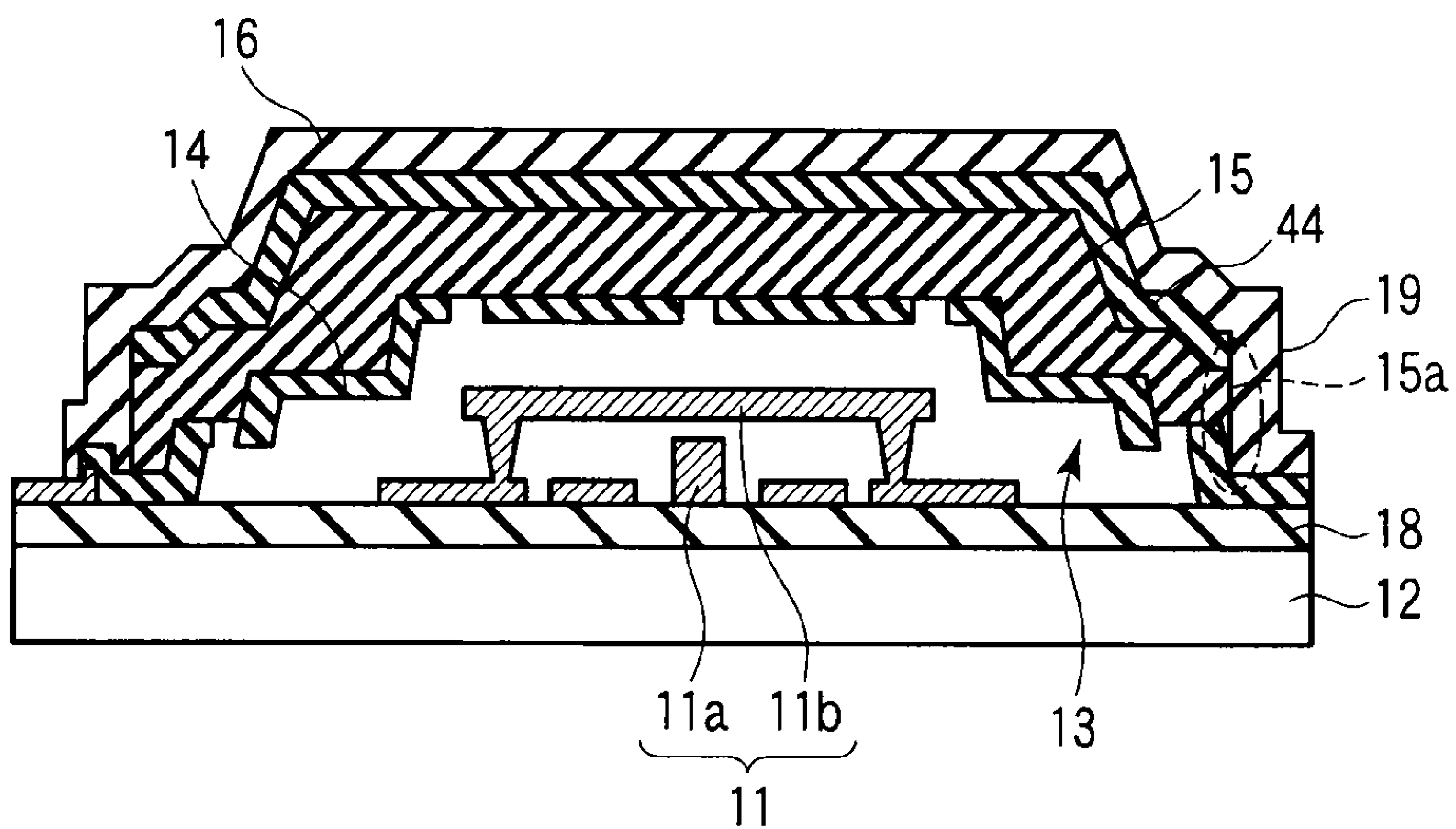
FIG. 5



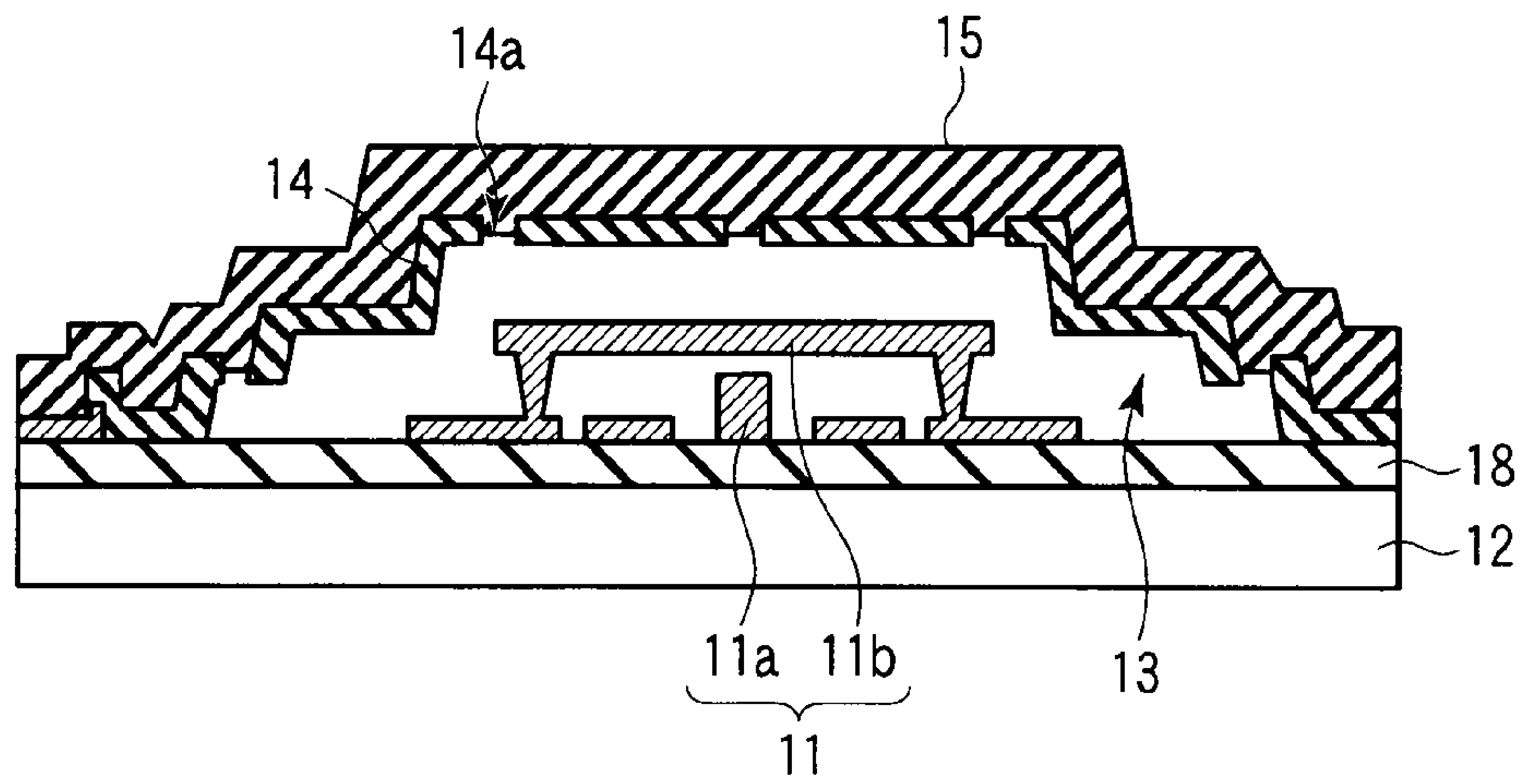
F I G. 6A



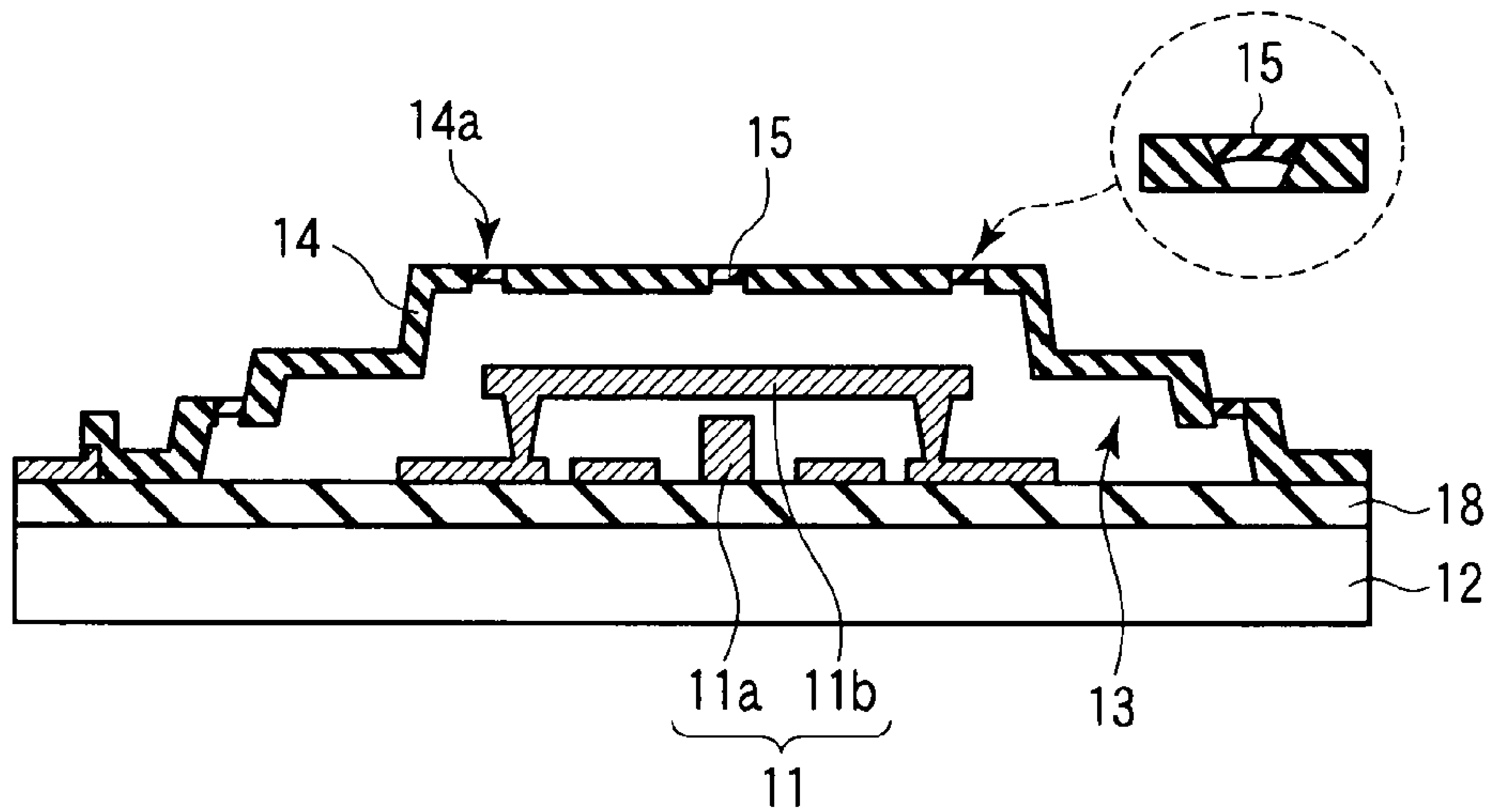
F I G. 6B



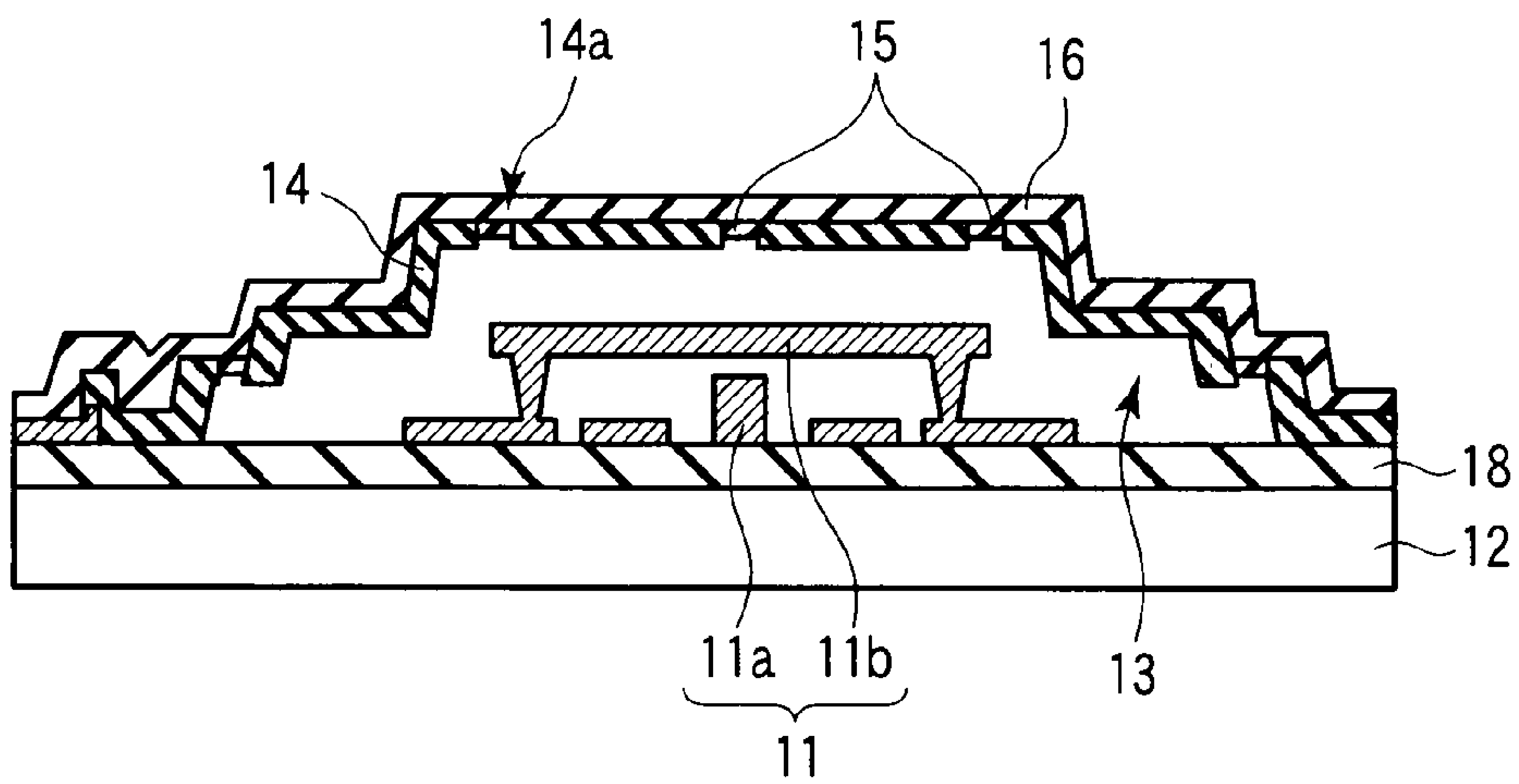
F I G. 6C



F I G. 7A



F I G. 7B



F I G. 7C

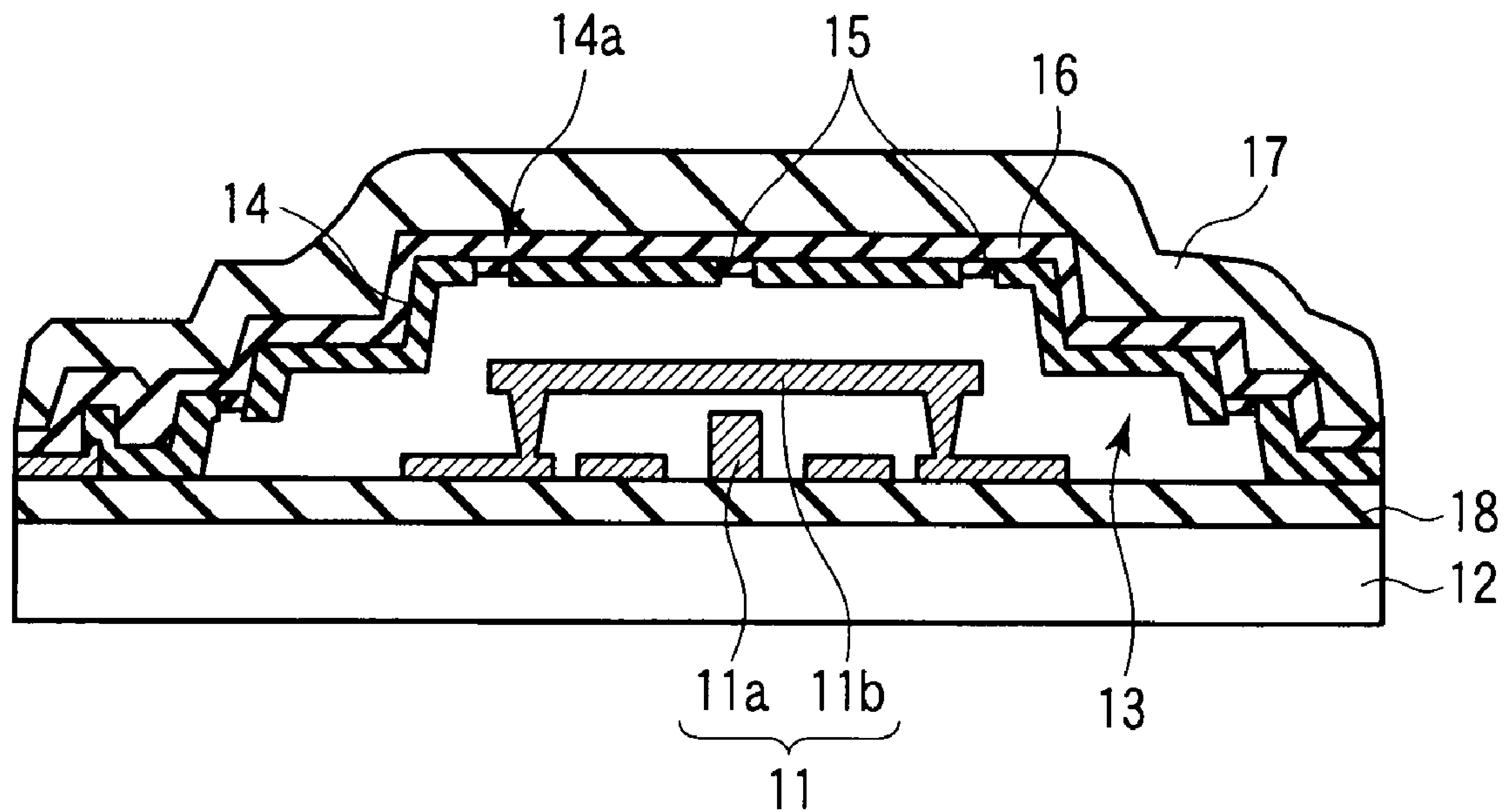


FIG. 8

	Young's modulus (Gpa)	Coefficient of thermal expansion(CTE)(ppm)
SiN	240.0	2.8
SiO	76.0	0.5
Epoxy resin	3.2	50.0

FIG. 9

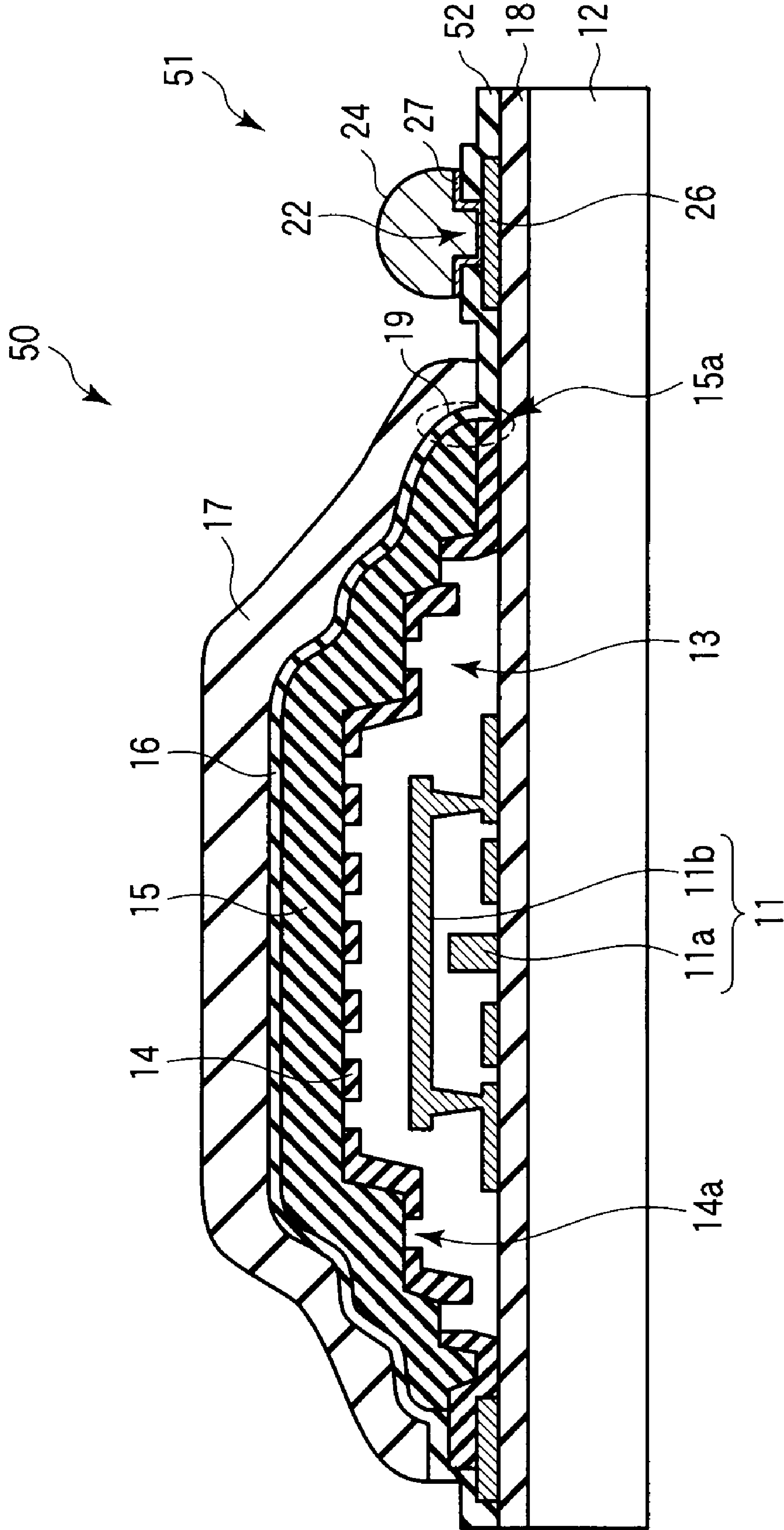


FIG. 10

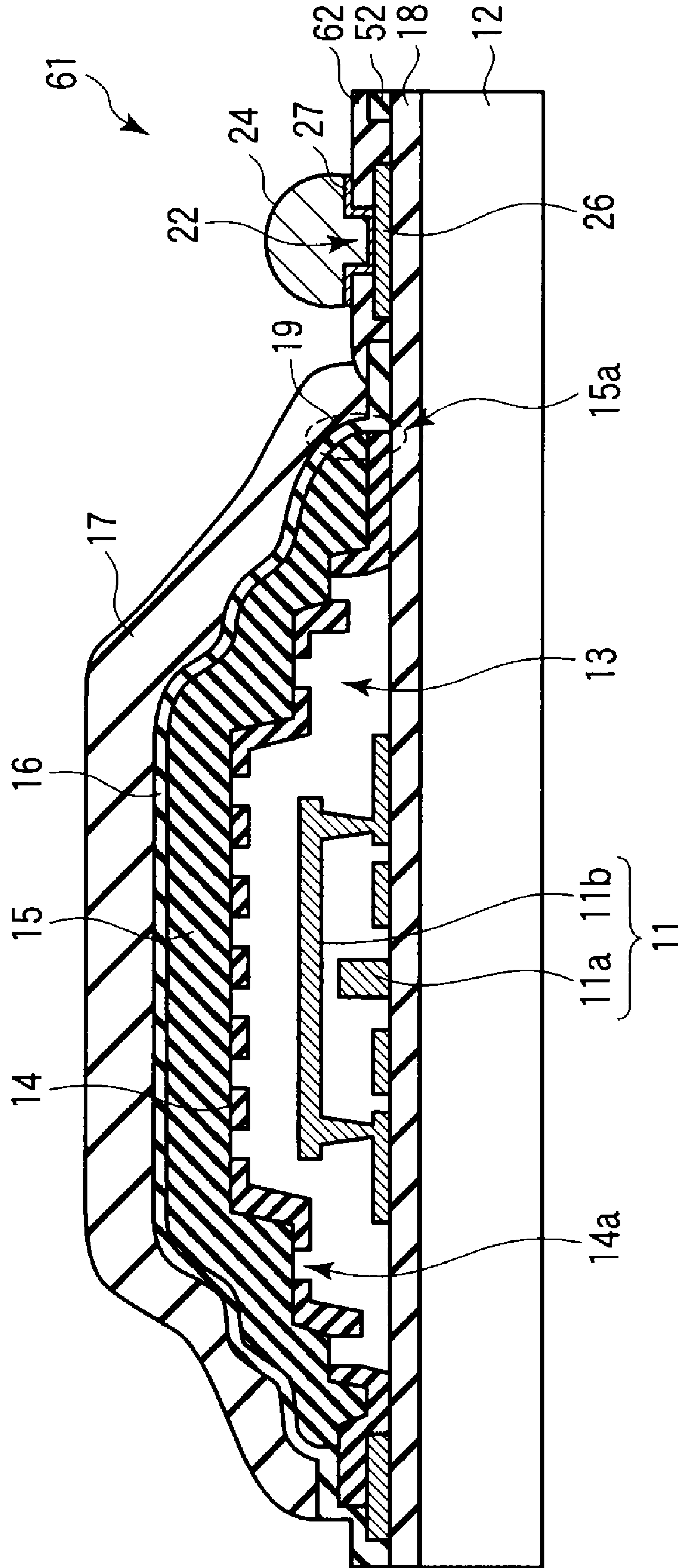


FIG. 11

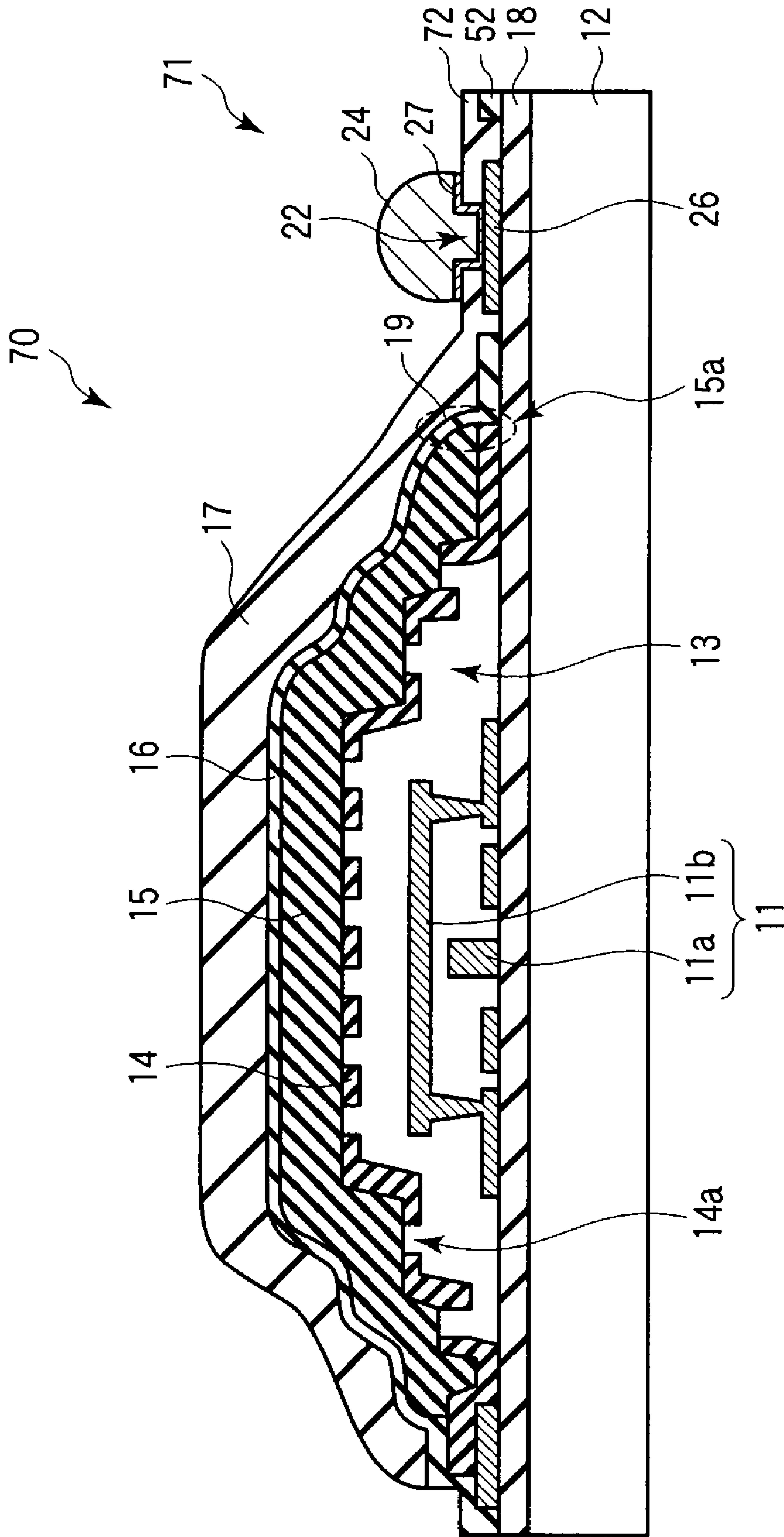


FIG. 12

ELECTRICAL DEVICE INCLUDING A FUNCTIONAL ELEMENT IN A CAVITY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from prior Japanese Patent Applications No. 2008-015510, filed Jan. 25, 2008; and No. 2008-282499, filed Oct. 31, 2008, the entire contents of both of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

Since a micro electro mechanical system (MEMS) is a functional element having a movable part, the MEMS needs a cavity as an operation space for the movable part, and the cavity is airtightly sealed so as to prevent the intrusion of outside air and protect the functional element.

2. Description of the Related Art

A functional element which is airtightly sealed in a cavity formed by etching a sacrificial film on a substrate has been known. As regards the functional element disclosed in JP 2006-7459, a functional element on a silicon substrate is covered with a sacrificial film, and an etching-resistant film having an opening on the sacrificial film is formed. Etching the sacrificial film through the opening forms the cavity by means of the sacrificial film, and the functional element is stored in the cavity. After this, since a silicon nitride film is formed on the sacrificial film, the opening is sealed, and then the inside of the cavity is airtightly sealed.

However, in the technique disclosed in JP 2006-7459, since the silicon nitride film has strong compression force to a Si substrate, an etching-resistant film forming a cavity is deformed, and the cavity deforms with time.

The stress of the film is lowered by thinning a silicon nitride film to be used in the sealing the opening. However, in a case where the silicon nitride film is thinned, it is needed to make the size of the opening sufficiently small so as to prevent the silicon nitride film dropping into the cavity from the opening and to seal the opening. Therefore, the technique has a problem that it takes a long time to remove the sacrificial film from the small opening and that the sacrificial film remains in the cavity due to a shortage of etching. Thus, an electrical device with a higher reliability has been desired.

BRIEF SUMMARY OF THE INVENTION

According to a first aspect of the invention, an electrical device may include a substrate including a functional element; an insulating first film configured to form a cavity containing the functional element, together with the substrate, and to include a plurality of through-holes; an insulating second film configured to cover the plurality of the through-holes, the second film being formed on the first film and having a gas permeability higher than that of the first film; an insulating third film configured to form at least on the second film, the third film having a gas permeability lower than that of the second film; and an insulating fourth film configured to form on the third film, the fourth film having an elasticity higher than that of the third film.

According to a second aspect of the invention, a electrical device may include a substrate including a functional element; an insulating first film configured to form on the substrate, the insulating first film forming a cavity containing the functional element and including a plurality of through-holes; an insulating second film configured to form in the through-holes, the second film covering each of the plurality of the through-holes and having a gas permeability higher than that of the first film; an insulating third film configured to form on the first and the second films, the third film having a gas permeability lower than that of the second film; and an insulating fourth film configured to form on the third film, the fourth film having an elasticity higher than that of the third film.

According to a third aspect of the invention, a method of an electrical device may include forming an insulating first film having a plurality of through-holes on a substrate with a functional element, the first film forming a cavity which contains the functional element, together with the substrate; forming an insulating second film on the first film to cover the plurality of the through-holes, the second film having a gas permeability higher than that of the first film; discharging water vapor in the cavity to outside of the second film after formation of the second film; forming an insulating third film on the second film after discharging the water vapor, the third film having a gas permeability lower than that of the second film; and forming an insulating fourth film on the third film, the fourth film having an elasticity higher than that of the third film.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. **1** is a cross-sectional view depicting an electrical device of a first embodiment of the invention;

FIGS. **2**A-**2**D, FIGS. **3**A-**3**C, and FIGS. **4**A and **4**B are cross-sectional views depicting in turn principles of manufacturing processes of the electrical devices of the first embodiment;

FIG. **5** is a cross-sectional view depicting a principle of a manufacturing process of an electrical device of a modified example of the first embodiment;

FIGS. **6**A-**6**C are cross-sectional views depicting in turn principles of manufacturing processes of electrical devices of the modified example of the first embodiment;

FIGS. **7**A-**7**C are cross-sectional views depicting in turn principles of manufacturing processes of electrical devices of a second embodiment;

FIG. **8** is a cross-sectional view depicting a principle of the manufacturing process of the electrical device of the second embodiment;

FIG. **9** is a view depicting characteristics of materials to be applied to the electrical device of the invention;

FIG. **10** is a cross-sectional view depicting an electrical device having another electrode unit of an embodiment of the invention;

FIG. **11** is across-sectional view depicting an electrical device having another electrode unit of the embodiment of the invention; and

FIG. **12** is a cross-sectional view depicting an electrical device having another electrode unit of the embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, embodiments of the invention will be described with reference to the drawings.

First Embodiment

An electrical device of a first embodiment of the invention will be described with reference to FIG. **1** to FIGS. **4**A and

4B. FIG. **1** shows cross sectional views illustrating the electrical devices, and FIGS. **2A**, **2B**, **2C** and **2D** to FIGS. **4A** and **4B** show cross-sectional views illustrating in turn principles of manufacturing processes of the electrical device.

As shown in FIG. **1**, an electrical device **10** is composed of a substrate **12** having a functional element **11**; an insulating first film **14** which forms a cavity **13** containing the functional element **11**, together with the substrate **12**, and has a plurality of through-holes **14***a*; and an insulating second film **15** which is formed on the first film **14** by covering upper surfaces of the plurality of through-holes **14***a* and has a gas permeability higher than that of the first film **14**.

Further, the device **10** is composed of an insulating third film **16** which is formed on the second film **15** and has a gas permeability smaller than that of the second film **15**; and an insulating fourth film **17** which is formed on the third film **16** and has an elasticity larger than the third film **16**.

The substrate **12** is, for example, a silicon substrate, and an insulating film **18** on the substrate **12** is, for example, a silicon oxide film. The functional element **11** is formed on the insulating film **18**. The functional element **11** is, for example, an electrostatic-drive-type MEMS variable-capacitance capacitor.

The MEMS variable-capacitance capacitor is, for example, composed of a first electrode **11***a* made of aluminum and a second electrode **11***b* made of aluminum facing the first electrode **11***a*. When a voltage is applied between the first and the second electrodes **11***a*, **11***b*, the capacity of the variable-capacitance capacitor is varied because the distance between the first and the second electrodes **11***a*, **11***b* varies due to an electrostatic force.

The cavity is an area for securing an operation space of the functional element **11**. The interior of the cavity **13** is maintained at a dry atmosphere or at an evacuated atmosphere. Thereby, the deterioration of the first and the second electrodes **11***a*, **11***b* made of aluminum by a harmful gas, for example, water vapor (moisture) is prevented, and the characteristic deterioration of the MEMS variable capacity capacitor is prevented. In the embodiment, aluminum is used for an electrode material as an example. However it is desirable, for reducing a phenomenon of a gradual creep, resulting from plastic deformation accompanied by an improvement of electrical reliability and an increase in the number of times of operations, to use an aluminum alloy containing copper (Cu).

The first film **14** is a silicon compound consisting mainly of Si—O bonds, for example, a silicon oxide film with a thickness of around 1 μm, and an inorganic film as a cap for protecting the device **11** from the outside.

The plurality of through-holes (openings) **14***a* of the first film **14** form the cavity **13** by removing a sacrificial layer through etching after forming the element **11**, as mentioned below. That is, the sacrificial layer is etched through the through-holes **14***a*.

The second film **15** is an organic layer, for example, an ultraviolet-curable resin consisting mainly of carbon, and more specifically, a resin film composed of a prepolymer, a monomer, a photo polymerization initiator, an additive agent, etc. The second film **15**, as described later, coats the first film **14** by covering the upper surfaces of the through-holes **14***a* after forming the cavity **13**. Further, the second film **15** has a function of discharging the harmful gas in the cavity **13** to adjust the atmosphere in the cavity **13**.

Therefore, it is preferable for the gas permeability of the second film **15** to be higher than that of the first film **14** and higher in response to the interior capacity of the cavity **13** so that the harmful gas such as water vapor is discharged in a short time from the cavity **13**.

That is, if it is assumed that the size of the cavity **13** storing the functional element **11** as represented by the MEMS is, for example, about 2×2×0.04 mm, it is desirable from a practical standpoint for the gas permeability, for example, as regards the water vapor permeability of the second film **15**, to be higher than 1×10^{-15} m^2/s.

The third film **16** is an inorganic film coating the upper surface of the second film **15**. The third film **16** is a silicon compound consisting mainly of Si—N bonds, with a gas permeability which is lower than that of the second film **15**, for example, a silicon nitride film, and prevents intrusion of the harmful gas such as water vapor into the cavity **13** by penetrating the second film **15**.

The silicon nitride film is a fine film, its gas permeability is very low, and the permeability of a gas through a thin film, for example, with a thickness which is thinner than 1 μm, is negligible.

The film stress of the silicon nitride film is large with 1.5 GPa degree. Therefore, to prevent the temporal deformation of the first film **14** due to film stress, it is desirable for the film thickness of the silicon nitride film to be set to 0.3 μm or less. To secure a film quality without any pinholes, etc., it is desirable for the film thickness of the silicon nitride film to be set 0.1 μm or more.

Further, the whole periphery of a side surface **15***a* of the second film **15** is covered with an insulating fifth film **19** having a gas permeability lower than that of the second film **15**. The fifth film **19** is a film made of the same material as that of, for example, the third film **16**. Therefore, the device **10** may prevent intrusion of a harmful gas such as water vapor into the film from the side surface **15***a* of the second film **15** to intrude into the cavity **13** by introducing the fifth film **19**.

The fourth film **17** is an organic film, for example, an epoxy resin, reinforces a mechanical strength of a cavity structure having the first to third films **14**, **15**, **16**, prevents the silicon nitride film from being cracked by a thermal stress, and secures thermal stability.

An electrode unit **20** for electrically connecting the functional element **11** to the exterior is formed outside the second film **15**. The electrode unit **20** is composed of a wiring **21**, an organic film **23**, a bump **24**, an insulating film **25**, an electrode pad **26**, and a metallic film **27**.

More specifically, one end **21***a* of the wiring **21** is connected to the functional element **11**, the other end **21***b* is extended outside the second film **15** along the substrate **12**, and constitutes the electrode pad **26**. The wiring **21** is made of, for example, aluminum, and is formed on the insulating film **18**.

The other end **21***b* of the wiring **21** is covered with the insulating film **25**. The film **25** is, for example, a silicon oxide film which is continuous to the first film **14**.

The organic film **23** is separated from the second film **15** by a distance L and formed on the insulating film **25**. The organic film **23** is, for example, the same ultraviolet-curable resin as the second film **15**. The organic film **23** and the insulating film **14** have an opening **22** corresponding to the electrode pad **26**.

The metallic film **27**, called an under bump metal (UBM), is formed on the electrode pad **26** in the opening **22**, and on the organic film **23** of an inner wall surface of the opening **22** and surroundings of the opening **22**. The metallic film **27** is a layered film, for example, of a nickel alloy and gold. The bump **24** is formed on the metallic film **27** inside and the periphery of the opening **22** in an overlap manner.

The metallic film **27** is formed so as to enhance the adhesiveness between the electrode pad **26** and the bump **24**, for example, made of a solder ball. That is, because an electrode pad **26** made of aluminum has a poor wetting property with a

bump **24** made of solder ball, it is hard to directly bond the electrode pad **26** to the solder ball.

The wiring (not shown) connected to the first electrode **11***a* of the device **11** has the same composition as that of the wiring **21**, thus a description thereof will be omitted.

According to the electrical device shown in FIG. **1**, the second film **15** having a higher gas permeability covering the upper surfaces of the through-holes **14***a* is a coating-type organic film. Thereby, even if the size (the diameter or the opening area) of each through-hole **14***a* is large, the second film **15** may surely seal each through-hole **14***a*.

Accordingly, since the sizes and arrangement of the through-holes **14***a* are not restricted, a plurality of arrangements of the through-holes **14***a* with large sizes enable surely etching the sacrificial film given below in a short time.

Since the third film **16** which is formed on the second film **15** and has a low gas permeability is a thin silicon nitride film, the device **10** may prevent intrusion of the harmful gas such as water vapor into the cavity **13**. Moreover, since the third film **16** has a small film stress, the device **10** may prevent the first film **14** from being deformed by the film stress of the silicon nitride film.

Further, since the fourth film **17** having large elasticity covers the thin silicon nitride film, the device **10** may increase the mechanical strength of the cavity structure and secure the thermal stability.

The side surface **15***a* of the second film **15** having a high gas permeability is covered with the fifth film **19** having the same low gas permeability as that of the third film **16**. Thereby, there is little possibility that the harmful gas such as water vapor intrudes into the cavity **13** from the side surface **15***a*. Therefore, to prevent the intrusion of the harmful gas such as water vapor into the cavity **13**, it is not needed to form the organic film **23** of the same kind as that of the second film **15** to be continuous to the second film **15**. Therefore, in a case in which a crack is produced from an edge of the metallic film **27** overlapping the organic film **23** to the organic film **23**, the device **10** may prevent the intrusion of the harmful gas such as water vapor to diffuse the gas from the organic film **23** into the second film **15** and the intrusion of the gas into the cavity **13**. In another aspect, when the second film **15** and the organic film **23** are made of the same material, it is preferable that the second film **15** and the organic film **23** are not continuous. If the second film **15** and the organic film **23** are not separated as in FIG. **1**, cracks generated below the bump **24** may be extended toward the cavity **13**. Thus, the second film **15** is not continuous to the organic film **23**, and more preferably, exposed side surface **15***a* is covered with the fifth film **19**.

A manufacturing method of the electrical device **10** will be described with reference to FIGS. **2**A, **2**B, **2**C and **2**D to FIGS. **4**A and **4**B.

As shown in FIG. **2**A, at first, an aluminum film is formed on the insulating film **18** of the substrate **12**. The aluminum film is patterned using a photolithography method, and the first electrode **11***a* of the element **11** and a part **11***c* of the bridge-shape second electrode **11***b* are formed.

A protective film (not shown) of a sacrificial layer etching described below is formed on the insulating film **18** including the upper surface and the side surface of the first electrode **11***a* and the part **11***c* of the second electrode **11***b*. The protective film is a layered film, for example, of a silicon nitride film having a thickness of 200 nm and an aluminum film of a thickness of 8 nm.

A first sacrificial film **41** covering the first electrode **11***a* and the part **11***c* of the second electrode **11***b* and having an opening at a position corresponding to a leg part of the second electrode **11***b* is formed. The first sacrificial film **41** is, for example, a polyimide film with a thickness of about 10 μm.

An aluminum film is formed on the first sacrificial film **41**, the aluminum film is patterned in the photolithography method, and the bridge-shape second electrode **11***b* is formed. The size of the second electrode **11***b* is, for example, around 2 μm×1200 μm.

As shown in FIG. **2**B, polyimide is coated again, and then, a polyimide film to be a second sacrificial film **42** is formed. A resist film (not shown) is formed on the polyimide film so as to cover an element forming part. Using the resist film as a mask, the polyimide film is etched, for example, using a reactive ion etching (RIE) method, and the second sacrificial film **42** of a thickness, for example, of 6 μm is formed. A selective ratio between the resist film and the second sacrificial film **42** composed of the polyimide film is, for example, 1.5-2.0. Thereby, the vicinity of the functional element **11** is covered with the first and the second sacrificial films **41**, **42**. For patterning the second sacrificial film **42**, a photosensitive material may be used. However, in such a case, the pattern edge becomes sharply-angled due to curing and contraction caused by an exposure process, which results in the introduction of cracks on the insulating film to be formed on the second sacrificial film **42**. Therefore, as mentioned above, it is preferable to perform patterning by using the resist film as a mask.

As shown in FIG. **2**C, an undoped silicon oxide film of a thickness of 1 μm is formed as the first film **14**, for example, in a chemical vapor deposition (CVD) method on a structure produced as the foregoing processing result. Thereby, the outside of the second sacrificial film **42** is covered with the first film **14**.

On the first film **14**, as shown FIG. **2**D, a resist film **43** having a plurality of openings **43***a* of each of which the diameters is, for example, about 10 μm is formed. Using the resist film **43** as a mask, for example, in the RIE method, a plurality of through-holes **14***a* are formed.

At this time, it is desirable for the shape of through-holes **14***a* to have a gradually increased diameter from the side of the second sacrificial film **42** toward the side of the resist film **43** by adjusting the selective ratio between the resist film **43** and the first film **14**. In other words, it is desirable for such through holes to have a taper shape in which the diameter gradually decreases from the side of the resist film **43** toward the side of the second sacrificial film **42** by adjusting the selective ratio between the resist film **43** and the first film **14**.

This is the reason improves the sealing characteristics of the through-holes **14***a* after removing the below mentioned first and second sacrificial films **41**, **42**.

As shown in FIG. **3**A, after the resist film **43** is peeled off by using, for example, an asher, the first and the second sacrificial films **41**, **42** are etched through the through-holes **14***a*. This etching is performed by plasma processing for about 15 minutes at a substrate temperature of 150° C. by using a mixed gas, for example, of oxygen (O_2) and CF_4. The removal of the first and the second sacrificial films **41**, **42** may be performed not only by the foregoing dry etching but also by applying wet etching using a chemical liquid.

Thereby, the cavity **13** with the functional element **11** stored therein is formed by the substrate **12** and the insulating first film **14** having the plurality of through-holes **14***a*.

As shown in FIG. **3**B, an ultraviolet-curable epoxy resin is applied as a photosensitive material to the structure produced as the result of the foregoing processing. The viscosity of the ultraviolet-curable epoxy resin is around 2,000-3,000 cp. Therefore, in a case where the film thickness of the first film **14** is 1 μm, and the diameter of each through-hole **14***a* is 10

μm, even when an epoxy resin of a thickness of 10 μm is formed on the first film **14**, there is no possibility of intrusion of the epoxy resin into the cavity **13** from the through-holes **14***a*.

After this, using photolithography, as shown in FIG. **3**C, an ultraviolet ray is irradiated for a short time to the ultraviolet-curable epoxy resin as a photosensitive material to pattern the resin. The resin is hardened by curing the resin, for example, at 200-250° C., and the second film **15** with a thickness of around 10 μm is formed. Thereby, the upper surfaces of the through-holes **14***a* are covered, and the cavity **13** is sealed. At this moment, the side surface **15***a* of the second film **15** is exposed.

For instance, by a hot plate, heat processing at en extent of around 150° C.×30 minutes is applied, the water vapor in the cavity **13** removed by penetrating throughout the second film **15** with large gas permeability. Thereby, the atmosphere in the cavity **13** is adjusted, for example, to a humidity not higher than 1%.

After this, as shown in FIG. **4**A, the third film **16** is formed on the second film **15** and on the side surface **15***a*. The third film **16** is, for example, a silicon nitride film (Si_3N_4) with a thickness of about 0.3 μm, and is formed in a low-temperature plasma CVD method of about 250-300° C. by using, for example, SiH_4 and NH_3 as process gases. Thereby, the third film **16** with excellent step coverage is formed.

In this way, the insulating third film **16** having small gas permeability on the second film **15**, and the insulating fifth film **19** having a low gas permeability covering the side surface of the second film **15** are formed at the same time, and the cavity **13** is airtightly sealed.

On the third film **16**, as shown in FIG. **4**B, for example, an epoxy resin, for example, with a thickness of around 100 μm is coated, and cured. Thereby, the third film **16** is protected, and the insulating fourth film **17** having elasticity is formed.

Using a well known method, the electrode unit **20** is formed. For instance, the wiring **21** and the first electrode **11***a* are formed at the same time, and the insulating film **25** and the first film **14** are formed at the same time. The organic film **23** and the second film **15** are formed at the same time, they are separated from each other by etching, and then the opening **22** is formed. The metallic film **27** is formed using a non-electric-field plating method. After this, the bump **24** thrusting into the metallic film **27** is formed.

In this way, an electrical device **10** in which the functional element **11** is stored in the cavity **13** is completed.

As described above, in the device **10** of the embodiment, the element **11** is stored in the cavity **13** formed by the layered structure of the first film **14**; the second film **15** with a gas permeability higher than that of the first film **14**; the third film **16** with a gas permeability lower than that of the second film; and the fourth film with an elasticity larger than that of the third film **16**.

As a result, the atmosphere in the cavity **13** can be easily adjusted. High airtightness of the cavity **13** may be obtained. Therefore, an electrical device **10** with high reliability may be produced.

While the case in which the first film **14** is a silicon oxide film (SiO_2) has been described, another silicon compound having Si—O bonds, such as a Low-k material (SiO_xC_y) and a silicon oxide nitride film (SiO_xN_y) may be used.

While the case in which the second film **15** having high gas permeability is an ultraviolet-curable epoxy resin has been described, it is possible to use an ultraviolet-curable acrylic resin as a substitute for the ultraviolet-curable epoxy resin. The well known thermosetting-type resin and electron-beam curing-type resin may be, for example, an epoxy acrylate resin, phthalate ester resin, etc.

Further, while the case where the third film **16** having low gas permeability has been a silicon nitride film (Si_3N_4), another silicon compound having Si—N bonds, such as a silicon oxide nitride film (SiO_xN_y) may be used.

In the case of the use of a silicon oxide nitride film, the third film **16** may be formed at a low temperature of 250-300° C. in plasma CVD using, for example, SiH_4, NH_3 and N_2O as process gases.

Further, a silicon carbide film (SiC), Aluminum oxide film (Al_2O_3), or an aluminum nitride film (AlN) may be adopted for use as the third film **16**.

If a silicon carbide film is used as the third film **16**, it is possible to form the third film **16** at a low temperature of 250-300° C. in plasma CVD using, for example, SiH_4 and CH_4 as process gases.

While the case of forming of the third film **16** in plasma CVD has been described, it is also possible to form the third film **16** in a sputtering method or a vacuum evaporation method.

Since the sputtering method or the vacuum evaporation method may not accurately perform step coverage at a part to be shielded, it is needed to uniformly form the third film **16** as a whole while rotating the substrate **12** by a planetary system.

Since it is not needed to heat the substrate, the sputtering method or the vacuum evaporation method has an advantage in that it may be used to form the third film **16** at a lower temperature in comparison with the plasma CVD method.

The fourth film **17** having a large elasticity is not limited to an epoxy resin, and a polyimide resin can be used.

While the case where the third film **16** and the fifth film **19** are formed at the same time has been described, they may be formed individually.

If the influence due to the harmful gas such as water vapor intruding from the side surface **15***a* of the second film **15** can be avoided, the fifth film **19** may be omitted.

While a method by heating in the case of removing the water vapor in the cavity **13** has been described, the invention is not limited to this method, and it is possible to store the cavity **13** in a container the inside of which is adjusted to a low-humidity atmosphere by means of a dried gas, and remove the water vapor in the cavity **13** in accordance with a partial pressure difference.

It is also able to discharge a gas from the cavity **13** and maintain the interior of the cavity **13** in a vacuum atmosphere.

If the inside of the cavity **13** is created in a vacuum atmosphere, a harmful gas other than water vapor, for example, an oxidation gas, a corrosive gas, may be removed from the cavity **13**. Thereby, in the use of the electrical device **10**, a characteristic deterioration or an occurrence of a failure of the functional element **11** may be prevented.

While the case in which the element **11** is the electrostatic-drive-type MEMS variable-capacitance capacitor has been described, the element **11** is not limited to this case, and it is possible for the element to be a piezoelectric-drive-type MEMS variable-capacitance capacitor. Further, another MEMS, for example, a film bulk acoustic resonator (FBAR) which holds a piezoelectric thin film between a lower electrode and an upper electrode and is formed on a substrate having the recession below a piezoelectric thin film so as not to disturb mechanical vibration may be used as the element **11**.

While the case in which the organic film **23** of the same kind as that of the second film **15** is formed on the pad **26** of

the electrode unit **20** through the insulating film **25** connected to the first film **14** has been described, the insulating film **25** may be omitted.

Modified Example

FIGS. **5**, **6**A, **6**B and **6**C each show a modified example of the first embodiment. In these modified examples, the same components as those of the first embodiment are designated by identical symbols, and only different components will be described.

In the first embodiment, the third insulating film **16** has been formed on the second insulating film **15**. Meanwhile, in each modified example, for example, a silicon oxide film **44** is formed between the second insulating film **15** and the third insulating film **16**. The oxide film **44** functions as a hard mask for processing the second film **15**.

FIGS. **6**A, **6**B and **6**C each show a manufacturing method of the modified example. In the modified example, the same processes as those of FIGS. **2**A to **3**B of the first embodiment are performed up to the processes of forming the second insulating film **15**.

As shown in FIG. **6**A, the silicon oxide film **44** having, for example, a thickness of around 2 μm is formed, for example, in the plasma CVD method on the second film **15**, and is made of the ultraviolet-curable epoxy resin, for example. A resist film **45** for processing the oxide film **44** is formed on the oxide film **44**.

As shown in FIG. **6**B, the oxide film **44** is etched, for example, in the RIE method as the resist mask **45**. After this, the second film **15**, which is outside the cavity **13**, is etched and the side surface **15***a* of the second film **15** is exposed through the plasma processing by using the silicon oxide film **44** as the mask.

After this, as shown in FIG. **6**C, a silicon nitride film as the third film **16** is formed on the oxide film **44** and on the exposed side surface **15***a* of the second film **15**. This forming method of the silicon nitride film is the same as that of the first embodiment. Then, in the same way as that of the first embodiment, the fourth film **17** and the electrode unit **20** are formed on the first silicon nitride film.

According to the foregoing modified example, the silicon oxide film **44** is formed as the hard mask for processing the second film **15**. Thereby, using the oxide film **44** enables thorough processing of the second film **15**. Further, forming the oxide film **44** enables improving the strength of the cavity **13**.

Second Embodiment

FIGS. **7**A, **7**B, **7**C and **8** each show a second embodiment. In the second embodiment, the same components as those of the first embodiment are designated by identical symbols, and only different components will be described.

In the first embodiment, the second film **15** has been formed on the entire surface, including the through-holes **14***a*, of the first film **14**. Meanwhile, in the second embodiment, the second films **15** are formed only in the through-holes **14***a*.

That is, as shown in FIG. **8**, the second films **15** are formed only in the through-holes **14***a* of the first film **14**, and the third film **16**, for example, composed of the silicon nitride film is formed on the first film **14** and the second film **15**. The fourth film **17**, for example, composed of epoxy resin is formed on the third film **16**.

A manufacturing method of the second embodiment will be described with reference to FIG. **7**A to FIG. **8**.

As shown in FIG. **7**A, after removing the first and the second sacrificial films **41**, **42** through the through-holes **14***a* of the first film **14**, the second films **15** are formed on the first film **14**. The second films **15** are coating-type organic materials, for example, ultraviolet-curable epoxy resins. The balance between surface tension of the material itself and at an internal and external pressure difference of the through-holes **14***a* and the cavity **13** prevents the second film **15** from intruding into the cavity **13**. Therefore, even in a structure in which the through-holes **14***a* are formed on the functional element **11**, the coating-type organic material is not formed in a film manner on the functional element **11**.

As shown in FIG. **7**B, By using a dry process such as a chemical dry etching (CDE) method and the RIE method, the second film is applied with etching, and the second films **15** are left only in the through-holes **14***a* of the first film **14**. In this way, the through-holes **14***a* are sealed by the second films **15**.

In the sealing process, it is possible to evacuate the cavity **13** and to fill in the cavity **13** with an inactive gas.

After this, as shown in FIG. **7**C, the third film **16** is formed on the first film **14** and the second films **15**. The third film **16** is formed as the silicon nitride film, for example, in a low-temperature plasma CVD method, for example, with a film thickness of several μm to 10 μm. The third film **16** is not limited to the silicon nitride film (AlN), and by using a method such as an ink jet method, it is possible to use a ceramic material such as an aluminum nitride film. In this way, covering the first film **14** and the second films **15** with the third film **16** enables preventing the intrusion of water vapor and dust into the cavity **13**, and enables preventing adverse affects on the functional element **11**.

If it is necessary, to secure an opening part for an electrode pad, the third film **16** may be patterned.

After this, as shown in FIG. **8**, epoxy resin having a thickness, for example, of about 100 μm is coated on the third film **16** and the third film is cured. Thereby, the insulating fourth film **17** for protecting the third film **16** and having elasticity is formed.

According to the second embodiment, the second films **15** composed of the coating-type organic material are formed only in the through-holes **14***a* of the film **14** which is composed of the inorganic film. That is, as shown in FIG. **9**, the epoxy resin as a coating-type organic material having a coefficient of thermal expansion (CTE) which is larger than that of the silicon oxide film and the silicon nitride film and having a Young's modulus which is smaller than that of the silicon oxide film and the silicon nitride film is formed only in the through-holes **14***a*. Therefore, since a volume of the epoxy resin which is extremely different in Young's modulus and CTE from the silicon oxide film and the silicon nitride film may be dramatically reduced, it is possible to prevent an occurrence of cracks in the silicon oxide film and the silicon nitride film due to the heat in process, and peeling off of the films. Accordingly, the reliability of the cavity **13** may be improved.

Modified Example

FIGS. **10** to **12** each show modified embodiments of the electrode unit **20** shown in FIG. **1**, and are cross-sectional views illustrating structures not having insulating films **25**. However, the wirings **21** are omitted in the views.

In an electrode unit **51** of an electrical device **50** shown in FIG. **10**, insulating film **52** of the same kind as that of the third film **16** is formed on the pad **26** to be continuous to the third film **16**. The insulating film **52** has the opening **22** reaching

the pad **26**, and the metallic film **27** is formed in the opening **22**. Further, the bump **24** is formed on the metallic film **27**.

In an electrode unit **61** of an electrical device **60** shown in FIG. **11**, organic film **62** of the same kind as that of the second film **15** is formed on the pad **26** so as to contact the fourth film **17**. The organic film **62** has the opening **22** reaching the pad **26**, and the metallic film **27** is formed in the opening **22**. Further, the bump **24** is formed on the metallic film **27**.

In an electrode unit **71** of an electrical device **70** shown in FIG. **12**, the organic film **72** of the same kind as that of the fourth film **17** is formed on the pad **26** to be continuous to the fourth film **17**. The organic film **72** has the opening **22** reaching the pad **26**, and the metallic film **27** is formed in the opening **22**. Further, the bump **24** is formed on the metallic film **27**.

As mentioned above, in each electrode unit **20**, **51**, **61**, **71**, if the organic films of the same kinds as those of the second films **15** are not formed to be continuous to the second films **15**, the structure of the electrode unit may vary.

According to the structures shown in FIGS. **10** to **12**, even when the insulating film **52**, and the organic films **62**, **72** have cracked from the edges of the metallic films **27** each overlapped to the insulating film **52**, and the organic films **62**, **72**, and the harmful gases such as water vapor enter from the cracks, the electrical devices **50**, **60**, **70** each may prevent the harmful gases such as water vapor from dispersing in the second films **15** and intruding into the cavity **13**.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. An electrical device comprising:
a substrate including a functional element;
an insulating first film configured to form a cavity containing the functional element, together with the substrate, and to include a plurality of through-holes, the cavity including a space between the insulating first film and the functional element;
an insulating second film configured to cover the plurality of the through-holes, the second film being formed on the first film and having a gas permeability higher than that of the first film;
an insulating third film configured to form at least on the second film, the third film having a gas permeability lower than that of the second film, the insulating third film being in contact with the insulating second film; and
an insulating fourth film configured to form on the third film, the fourth film having an elasticity higher than that of the third film.

2. The device of claim **1**, further comprising: an insulating fifth film configured to cover a side surface of the second film, the fifth film having a gas permeability lower than that of the second film.

3. The device of claim **2**, wherein the fifth film and the third film are films formed of the same material.

4. The device of claim **2**, further comprising, an electrode formed outside the second film.

5. The device of claim **2**, further comprising:
wiring of which one end is connected to the functional element and of which the other end is extended outside the second film; an organic film which is apart from the second film, covers the other end of the wiring and includes an opening corresponding to the other end of the wiring; and a bump which is formed on the organic film surrounding the opening and is connected to the other end of the wiring.

6. The device of claim **1**, wherein the first film is a silicon compound which consists mainly of Si—O bonds; the second film is any one of a thermosetting-type resin, an ultraviolet-curable resin and an electron-beam curing-type resin which consist mainly of carbon; the third film is a silicon compound which consists mainly of Si—N bonds; and the fourth film is one of an epoxy resin and a polyimide resin.

7. The device of claim **1**, wherein the second film closes each of the through-holes.

8. The device of claim **7**, further comprising:
an insulating fifth film configured to cover a side surface of the second film, the insulating fifth film having a gas permeability lower than that of the second film.

9. The device of claim **8**, wherein the fifth film and the third film are films formed of the same material.

10. The device of claim **8**, further comprising, an electrode formed outside the second film.

11. The device of claim **10**, further comprising:
wiring of which one end is connected to the functional element and of which the other end is extended outside the second film; an organic film which is apart from the second film, covers the other end of the wiring and includes an opening corresponding to the other end of the wiring; and a bump which is formed on the organic film surrounding the opening and is connected to the other end of the wiring.

12. The device of claim **7**, wherein the first film is a silicon compound which consists mainly of Si—O bonds; the second film is any one of a thermosetting-type resin, an ultraviolet-curable resin and an electron-beam curing-type resin which consist mainly of carbon; the third film is a silicon compound which consists mainly of Si—N bonds; and the fourth film is one of an epoxy resin and a polyimide resin.

13. An electrical device comprising:
a substrate including a functional element;
an insulating first film configured to form on the substrate, the insulating first film forming a cavity containing the functional element and including a plurality of through-holes, the cavity including a space between the insulating first film and the functional element;
an insulating second film configured to form in the through-holes, the second film covering each of the plurality of the through-holes and having a gas permeability higher than that of the first film;
an insulating third film configured to form on the first and the second films, the third film having a gas permeability lower than that of the second film, the insulating third film being in contact with the insulating second film; and
an insulating fourth film configured to form on the third film, the fourth film having an elasticity higher than that of the third film.

14. The device of claim **13**, further comprising: an insulating fifth film configured to cover a side surface of the second film, the fifth film having a gas permeability lower than that of the second film.

15. The device of claim **14**, further comprising: an electrode configured to form outside the second film, the electrode being electrically connected to the functional element.

16. The device of claim **15**, further comprising: wiring of which one end is connected to the functional element and of which the other end is extended outside the second film; an organic film which is apart from the second film, covers the other end of the wiring and includes an opening correspond-

ing to the other end of the wiring; and a bump which is formed on the organic film surrounding the opening and is connected to the other end of the wiring.

17. The device of claim **13**, wherein the first film is a silicon compound which consists mainly of Si—O bonds; the second film is any one of a thermosetting-type resin, an ultraviolet-curable resin and an electron-beam curing-type resin which consist mainly of carbon; the third film is a silicon compound which consists mainly of Si—N bonds; and the fourth film is one of an epoxy resin and a polyimide resin.

18. A method of an electrical device comprising:

forming an insulating first film having a plurality of through-holes on a substrate with a functional element, the first film forming a cavity which contains the functional element, together with the substrate, the cavity including a space between the insulating first film and the functional element;

forming an insulating second film on the first film to cover the plurality of the through-holes, the second film having a gas permeability higher than that of the first film;

discharging water vapor in the cavity to outside of the second film after formation of the second film;

forming an insulating third film on the second film after discharging the water vapor, the third film having a gas permeability lower than that of the second film, the insulating third film being in contact with the insulating second film; and

forming an insulating fourth film on the third film, the fourth film having an elasticity higher than that of the third film.

19. The method of claim **18**, wherein the discharging of the water vapor is performed by a thermal process.

20. The method of claim **19**, further comprising: exposing a part of the first film by removing a part of the second film after formation of the second film, the third film being formed on the first film and the second film.

21. The device according to claim **1**, wherein the function element includes an electrode movable in the cavity.

22. The device according to claim **21**, wherein the function element is constituted by a micro electro mechanical system (MEMS).

23. The device according to claim **13**, wherein the function element includes an electrode movable in the cavity.

24. The device according to claim **23**, wherein the function element is constituted by a micro electro mechanical system (MEMS).

25. The method according to claim **18**, wherein the function element includes an electrode movable in the cavity.

26. The method according to claim **25**, wherein the function element is constituted by a micro electro mechanical system (MEMS).

* * * * *